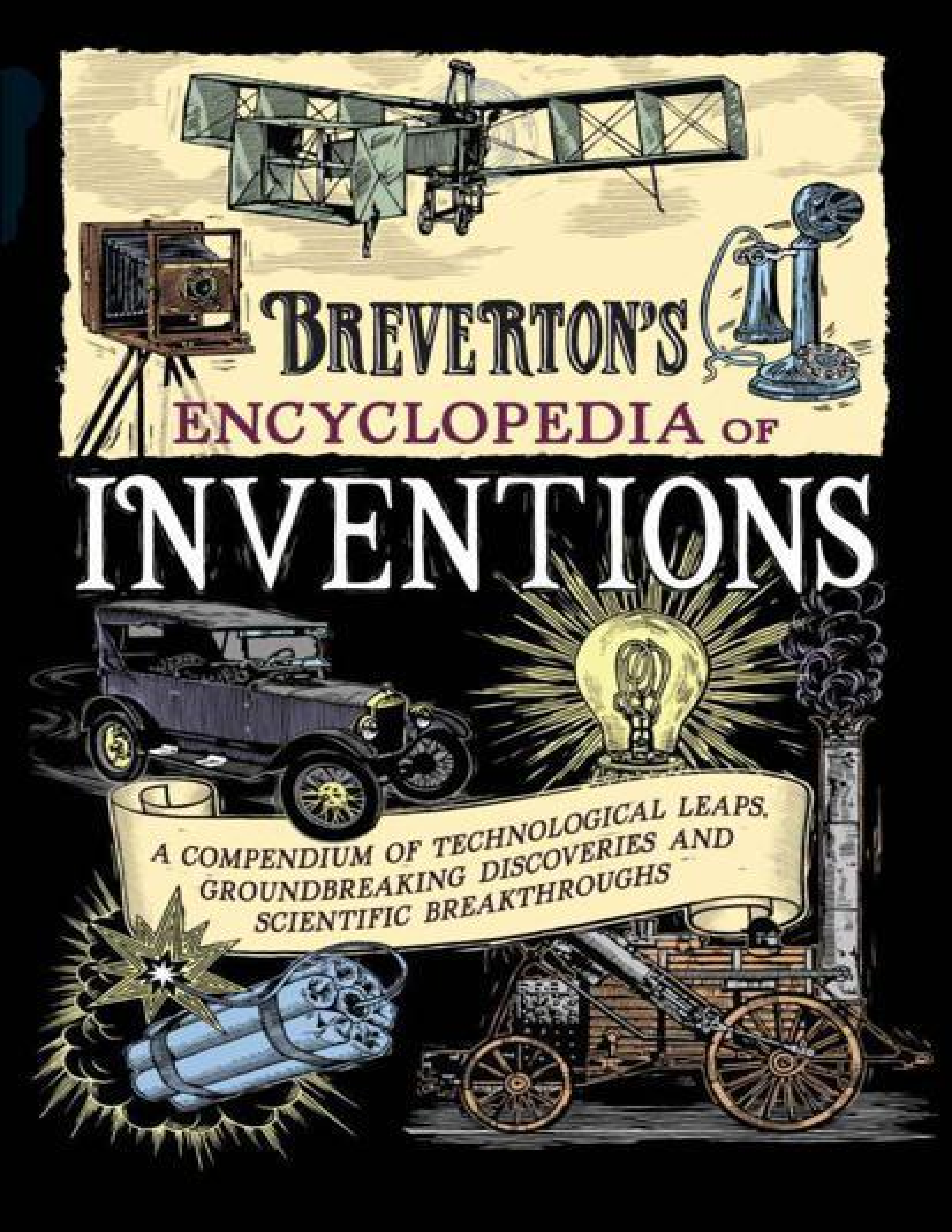
BREVERTON'S
ENCYCLOPEDIA OF
INVENTIONS
A COMPENDIUM OF TECHNOLOGICAL LEAPS, GROUNDBREAKING DISCOVERIES AND SCIENTIFIC BREAKTHROUGHS

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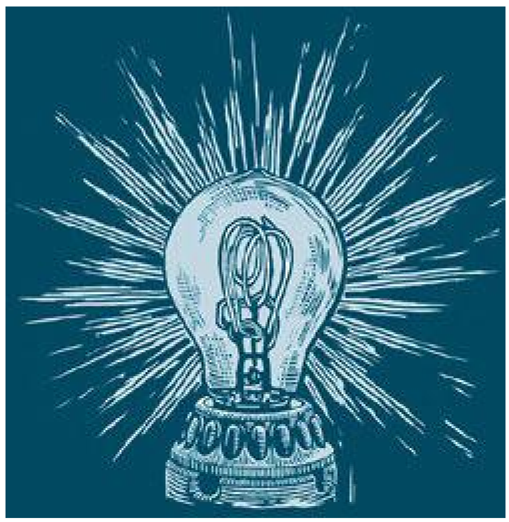

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A COMPENDIUM OF TECHNOLOGICAL LEAPS, GROUNDBREAKING DISCOVERIES AND SCIENTIFIC BREAKTHROUGHS

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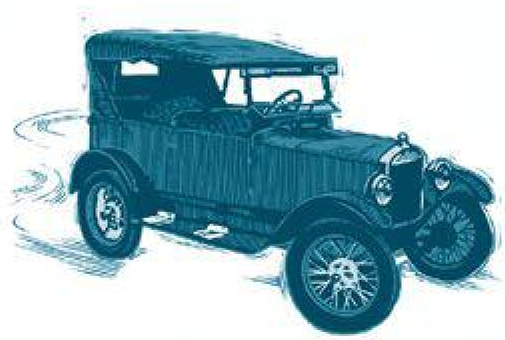
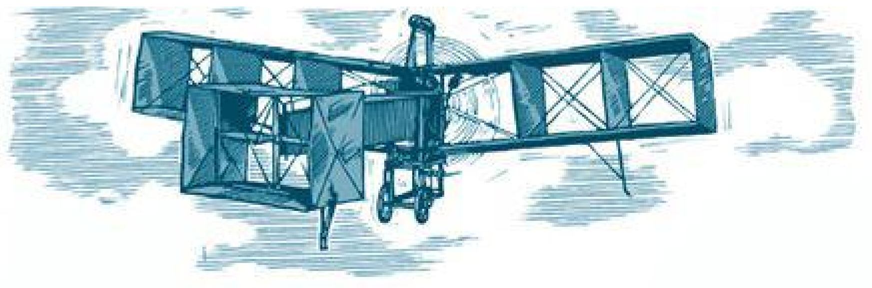


INTRODUCTION



This book tells us about the extraordinary discoveries and inventions that have contributed to knowledge and progress through breakthroughs in science and technology. The efforts and ingenuity of mankind – from the earliest, most basic of discoveries to today’s most cutting-edge – have shaped the modern world, and continue to allow the human race to evolve to reach its fullest potential.

All collections such as this are bound in some way to be subjective. For instance, does the discovery of a treatment for a rare form of cancer compare with the development of the ability to perform transplant operations? Also, for some inventions and discoveries we have specific times, places and individuals who are responsible, but where do we place, or even include, the discovery of how to make fire? Again, one would think that the invention of buttons enabled us to develop today’s clothing, but in fact it was the unknown 13th-century inventor of the buttonhole which allowed this.

UNKNOWN HEROES OF SCIENCE

Even when we come to ‘known’ inventors or discoverers, sometimes they are ‘*standing on the shoulders of giants*’, following on from a long line of original thinkers. In other cases, the wrong inventor has been attributed because he or she was better at innovating or marketing, or simply better-known. Thus, you will surprisingly read about Merlyn Pryce and the discovery of *Penicillium notatum* mould in 1928, and of the men and women who developed penicillin, the antibiotic agent which has saved millions of lives – and not Alexander Fleming. And the genius Nikola Tesla, carrying on the work of David Hughes, was really responsible for the

radio, not the commonly attributed Marconi. Equally, Joseph Swan, not Thomas Edison, developed the electric light bulb. There are more than 20 great ideas which changed today's world, which have been re-attributed in this text. Thus this is not a regurgitation or a re-hash of past books upon inventions and discoveries, but a genuine attempt to discover who has improved or changed our lives, and in what ways. I have attempted to include whoever has contributed in some major way to learning, medicine and the sciences in general. However, great artists are not included. Although we can quite easily say that Shakespeare or T.S. Eliot or Rembrandt have helped us advance culturally, we cannot say that they have changed the world in any concrete manner. Also, this book does not include only those who have altered the world for the better, but also those responsible for weapons of destruction. Sometimes an innovator rather than an inventor or discoverer has been included, where their contribution has been of major significance. Some entries are longer than others, such as those on the unknown, yet prolific, geniuses David Hughes and Richard Trevithick. This usually has been carried out in the interest of '*putting the record straight.*'

FROM PREHISTORY TO THE SCIENTIFIC AND INDUSTRIAL REVOLUTIONS

The book begins with prehistory – the knife, fish hook, cloth and sewing needle, quern-stone and bow and arrow. Then we move to the ancients – the Sumerians, Chaldeans, Egyptians, Greeks and Romans with mathematics, astronomy, theory of atoms, lever and astrolabe. It is astonishing how much was known, say, about the existence of atoms and their indestructibility at this time. Men knew that the Earth was round, and that it was not the centre of the Universe, but an incredible amount of knowledge was lost during the ensuing Dark Ages of Western civilization. However, during these centuries, the Chinese and Islamic worlds made great advances with clocks, gunpowder, medicine, surgery, gears, algebra, crankshafts and the compass. Then with the Renaissance in the Western world, we began to rediscover what had been lost. Gutenberg's printing press of 1336–40 began to disseminate scientific thought from the Arab world to the West, and the great Scientific Revolution took place in line with the Renaissance, with the conformist teachings of the church being slowly overthrown in many

aspects of life. This was the age of da Vinci, Copernicus, Galileo, Harvey, Boyle, Hooke and Newton – men who changed the world. In turn, this era of scientific curiosity, experimentation and discovery led to the Industrial Revolution, responsible for the modern age. We see the appearance of steam engines, textile machinery, the development of the factory system, electricity, pulped paper and the mechanized steel industry.

THE ACCELERATION OF INVENTION AND INNOVATION

In the 20th century, two World Wars spurred invention and discovery, often not for the good of mankind, but still a demonstration of man's incredible ability to invent and innovate. Since the Second World War we have seen huge advances in agricultural productivity, and are in the middle of an Information Revolution and the Electronics Age. The most exciting developments at present, and potentially the most problematical, are in health, disease treatment, genetic modification and medicine. Scientists are progressing towards the day when it will be possible to extend the life of humans, when many genetic diseases can be prevented, and when certain types of cancer can be cured or delayed. Every reader of this book can see that his or her life has altered in many ways because of the inventions and discoveries of their lifetimes and that of their parents. It is the reason for living – to improve rather than accept, to query rather than conform, so humankind can progress. To the inventors featured in this book, we all owe a debt of thanks. The scientific spirit has helped us move from forest shelters to where we are today, and will improve the lives of our children for generations to come.

CHAPTER 1

THE DAWN OF TECHNOLOGY

KNIFE

—— *c*.2,600,000 BCE ——

Australopithecine HOMINIDS, GONA, ETHIOPIA

The use of our first tools assured human survival, and the appearance of stone knives marks the beginning of the archaeological record. Since they can be used for cutting, slashing, spearing and pricking, knives have many uses in feeding and defending humankind. For millennia, knives were essential for hunting and butchering animals. The first stone tools were thought to be the ‘Oldowan’ tools found in the Olduvai Gorge in Tanzania by Louis Leakey in the 1930s. They were made by the extinct hominid *Homo erectus* between 1.7 and 2.4 million years ago. However, tools of a similar type were found in the Gona fossil fields in Ethiopia in the 1970s, and they have been dated to 2,600,000 BCE. The discoveries provided strong evidence that toolmaking, once thought to be a skill special to the *Homo* genus, began long before its emergence, perhaps by half a million years. (*Homo sapiens*, the only surviving hominid, originated in Africa only around 200,000 years ago, and reached full behavioural modernity only 50,000 years ago.)

It is a reasonable assumption that the tools were made by more primitive members of the human lineage, the *Australopithecines*, the only hominids known to have existed at that time. These stone tools generally consisted of sharp flakes battered off a stone core, but early hominids also carried out more sophisticated flaking and reshaping to sharpen and straighten their blades. Because of its role as humankind’s first tool, many cultures have attached spiritual and religious significance to the knife. To produce an Oldowan tool, a roughly spherical hammerstone was struck on the edge, or striking platform, of a suitable core rock, to make a ‘conchoidal fracture’ with sharp edges useful for various purposes. Originally made of rock, flint or obsidian (a naturally occurring volcanic glass), knives evolved in

construction. Stone knives would later be lashed onto a bone or wooden handle to make them easier to use.

THE MOST IMPORTANT TOOLS OF ALL TIME

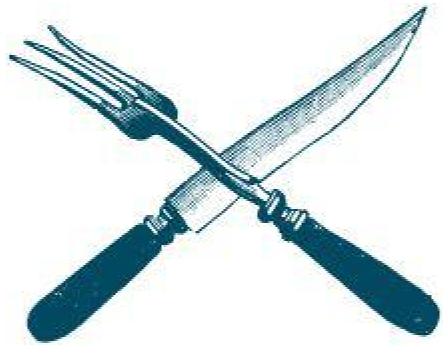
THE CHISEL, the lathe, the saw, the scythe, the scalpel and the sword are all forms of the knife, specialized for different circumstances. In 2005 Forbes.com readers and a panel of experts rated the knife as the most important tool of all time in terms of its effect on civilization. In order, the 20 most important tools were the knife, abacus, compass, pencil, harness, scythe, rifle, sword, eyeglasses, saw, watch, lathe, needle, candle, scales, pot, telescope, level, fish hook and chisel.

AMERICAN EATING HABITS

WHEN THE FIRST colonists sailed to America, food was still eaten by cutting it up with knives and spearing it to bring it to the mouth. Even by the beginning of the 18th century, very few forks were exported from Europe to America. However, knives were being imported and their tips became progressively blunter. Because Americans had very few forks and no longer had sharp-tipped knives, they had to use spoons in place of forks. They would use the spoon to steady the food as they cut it and then switch the spoon to the opposite hand in order to scoop up food to eat. This distinctly American style of eating, by cutting the meat or fish into bite-size portions before beginning the meal, has continued even after forks became commonplace in the United States.

Around 10,000 years ago, modern humans found out how to make knives out of copper, and *c*.5,000 years ago, craftsmen in the Near East began to make them from bronze. These knives consisted of a piece of metal that was sharp at one end (the blade), and dull at the other (the tang). Usually a wooden or bone handle would be crafted around the tang to make it easier to hold. Later, knives were made out of harder iron and steel, and more recently titanium and ceramics have been used. Knives were principally used for eating, as forks are a fairly recent invention. In 1669, in a bid to cut down violence, King Louis XIV of France decreed that all pointed knives on the street or the dinner table were illegal, and ordered all knife points

ground down. This is why dinner knives are even now blunt-tipped. Today many English doctors are campaigning for a ban on long-pointed kitchen knives to reduce the number of deaths from stabbing.



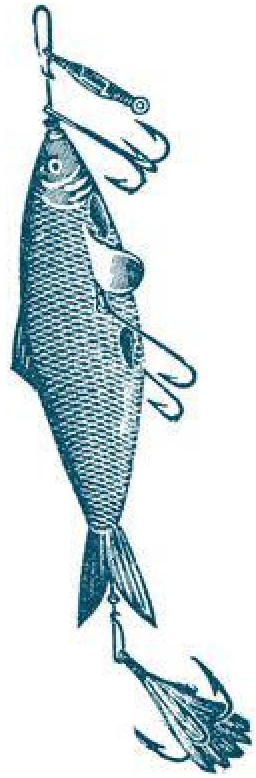
FISH HOOK

—— *c*.30,000 BCE ——

CRO-MAGNON MAN, ACROSS EUROPE

Fish have been a rich source of protein, fat and fatty acids since the dawn of time, and they also have the advantage that they can be caught without the risks attendant upon hunting wild beasts. The direct antecedent of our fish hook was a device that archaeologists call a *gorge*. This was a bit of spindle-shaped bone or wood, notched in the centre so that a line could be tied to it. A gorge was pushed into a chunk of bait, the fish was allowed to swallow it, and when the line was tugged, the gorge set cross-wise inside the fish and it was hauled in. One of the earliest types of gorge was unearthed 22 feet (6.7 m) below the surface in a peat bed in the valley of the Somme in France. It was believed to be about 7000 years old. The earliest fish hooks date from around 30,000 BCE, and they were variously made from wood, animal bone or horn, human bone or shells. In addition to hooks made out of one piece of wood, stone or bone, stone-age man often made compound hooks, with components (often of different materials) tied together. Compound hooks were stronger than the other types. It is easy to break a slender, rounded bone hook, but a securely tied compound hook can withstand tension better. It appears that the oldest hooks were made without barbs or any other refinement. Archaeologists believe that the idea for adding a barb to the hooks was derived from the spear. Barbs gave the

hooks more holding power just as a barbed spearpoint was harder for an animal to dislodge.



ROMAN FLY FISHING

‘THEY WRAP *dark red wool round a hook and tie on to it two feathers which grow under the wattles of a cock and resemble wax in colour. The fishing rod is six feet in length and the line the same. When the tricky fly is lowered a fish is attracted by the colour and rises madly at the pretty thing that will give him a rare treat, but on opening his jaws is pierced by the hook, and is given poor enjoyment of the feast when he is captured*.’ Claudius Aelianus, *On the Nature of Animals*, *c*.175–*c*.235 CE

Not until hooks found in Norway and Denmark, dating from about 7000–8000 years ago, do we find them equipped with barbs, grooves or holes to make the attachment of the bait and line simple. Since wood floats, the hook would probably have had to be fastened to a stone or a similar weight to make it sink. However, some fish will take a floating hook. Up until the end of the 19th century, Lapp fishermen used wooden hooks in the great

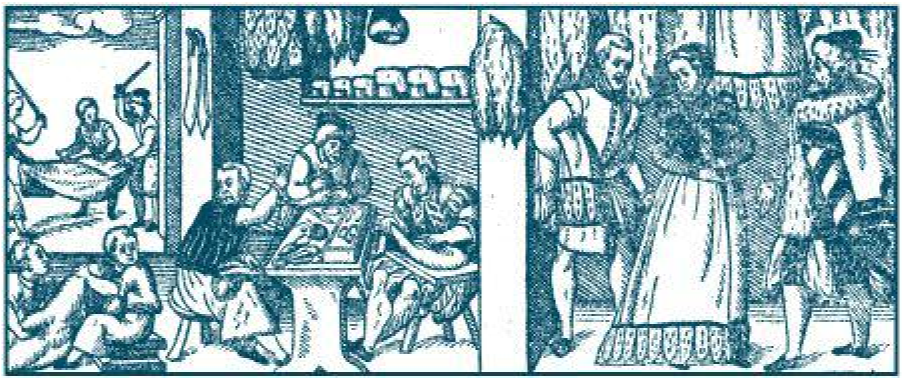
cod fisheries of northern Norway. They carved their hooks out of tough juniper wood, and burned the point to make it hard. Native Americans used the claw of a hawk and the beak of an eagle to make hooks. Metal hooks generally replaced other materials, but British fishermen until recently used hawthorn hooks to catch flounders, and until the 1960s Norwegian and Swedish fishermen used three-pronged juniper hooks to catch burbot. They claimed that the smell of juniper actually attracts the fish and also that the burbot has a tendency to spit out ordinary steel hooks. Today the hook is becoming less important as commercial fishing relies more and more upon massive nets, although certain industrial fishing techniques, such as longline fishing, still depend upon the hook. Sports fishermen usually use bait and lures.

SEWING NEEDLE

—— *c*.30,000 BCE ——

PALEOLITHIC ERA, RUSSIA

Clothing made using a sewing needle succeeded knotted and tied animal skins to protect man from the elements. This enabled humankind to move out of Africa into colder climates. The earliest clothing consisted of fur, leather and leaves of grass that were draped, wrapped or tied around the body. Anthropologists have conducted a genetic analysis of human body lice, which suggests that clothing originated quite recently, around 107,000 years ago. Lice are an indicator of clothes-wearing, since humans have sparse body hair, and lice generally require the presence of human clothing in which to survive. Research suggests that the invention of clothing may have coincided with the northward migration of modern *Homo sapiens* out of Africa around 100,000 years ago. Another group of scientists estimates that clothing originated around 540,000 years ago. Some human cultures such as the Inuit until recently made their clothing entirely of prepared and decorated furs and skins. Other cultures supplemented or replaced leather and skins with cloth: either woven, knitted or twined from various animal and vegetable fibres. Clothing materials deteriorate quickly compared to solid artefacts, but in 1988 in Russia archaeologists found bone and ivory sewing needles dating from 30,000 BCE.



Knitting and crochet are thought to have begun when primitive people sought to make webs out of roots and tendrils, a skill which evolved into hand-knitting wool. Making fabrics such as linen (from flax) by hand was always a laborious process, and the textile industry was the first to be mechanized in the Industrial Revolution, with the invention of the powered loom (*see* Arkwright 1771, and Cartwright 1785). Different cultures evolved various ways of creating clothes. As cloth of any description was handmade and thus expensive, it was essential to keep it uncut if possible for other uses or users. The Greeks and Romans draped togas over their bodies, and many people still wear garments consisting of rectangles of cloth wrapped around them, e.g. in the Indian subcontinent we see men wearing the dhoti and women the sari. These garments are simply tied up, but the Scottish kilt is held in place by a belt and pins. The expensive cloth remains uncut, and different people of various sizes can wear such a garment. Another approach involves cutting and sewing the cloth, but using every bit of the cloth rectangle in making the clothing. The tailor may cut triangular pieces from one corner of the cloth, and then add them elsewhere as gussets, e.g. in men's shirts. There are said to be four primary factors in clothing comfort, identifiable as the '*4 Fs of Comfort*': (1) fashion; (2) feel; (3) fit; and (4) function. Mark Twain acknowledged the importance of clothing in *More Maxims of Mark* (1927): '*Clothes make the man. Naked people have little or no influence in society*.'

THE ORIGIN OF 'COLOURLESS'

DURING THE Napoleonic Wars, women formed 'knitting groups' and knitted socks and mittens for the soldiers. This practice continued through the First and Second World Wars. They also knitted garments for the poor

of the parish, usually in neutral colours of grey and beige. Colour was considered to be a status symbol, so the wearer’s drab clothes were called ‘colourless’, which term is still used as a disparaging adjective today.

QUERN-STONE

— *c*.9500–9000 BCE —

MESOLITHIC MAN, SYRIA

Stone hand-grinders were the first foodprocessors, enabling the conversion of grains to food and the spread of agriculture across the world. They were also the ancestors of millstones. Quern-stones were used in pairs. The upper stone was originally rotated by hand and called a *hand-stone*. The lower stationary stone was the *quern*, and they were first used to grind grains into flour for making bread. The rotation causing grinding is known as *milling*, and quern-stones were later replaced by millstones, as the watermill and windmill were invented. However, animals were later used to operate large millstones.

The *saddle quern* was the earliest form of quern. The saddle quern is produced by rocking or rolling the hand-stone using parallel motions, which forms a shape like a saddle. These hand-stones can be either roughly cylindrical like a rolling pin (used with both hands), or rough hemispheres (used with one hand). Either provided a crushing motion, not a grinding action, both being more suitable for crushing malted grain, but not suitable for producing flour. The next development was the *rotary quern* for grinding, of which there are several forms. This quern used circular motions to grind the grain, so both the quern and the hand-stone were generally circular. The hand-stone of a rotary quern is much heavier than that of saddle quern, providing the necessary weight for the grinding of unmalted grain into flour. In some cases the grinding surfaces of the stones fit into each other, the upper stone being slightly concave and the lower one convex.

There was also a type of rotary quern known as a *beehive quern*. Here, the upper stone is hemispherical, with a central conical hopper to hold the grain that falls down a hole to the grinding surface. It is held in position with a pivot that fits into a central hole in the bottom stone. The upper stone also has a deep horizontal socket in its steep side in which to place the

wooden peg used as a handle to rotate or oscillate the upper stone. This was the earliest type of rotary quern to appear in the British Isles, around 350 BCE. Larger querns were developed that were operated by two men or slaves pushing a bar around a large quern-stone. The men were later replaced by oxen, donkeys or horses. Today's pestle and mortar, used for grinding herbs in the kitchen, is a descendant of the quern-stone. As well as grain, a wide range of foodstuffs and inorganic materials were processed using stone querns or mortars, including nuts, seeds, fruit, vegetables, herbs, spices, meat, bark, pigments, dyes, medicines, cosmetics and clay. They were also used to grind metal ores such as gold, after mining extraction. This process would liberate fine ore particles which could then be separated by washing, prior to smelting. Tobacco used to be popular as *snuff*, a fine powder ground in a quern-stone and inhaled via the nose.

MILLSTONE GRIT

THE FAVOURED type of stones from which to manufacture quern-stones are hard igneous rocks such as basalt. These have naturally rough surfaces, but stone grains do not detach themselves easily, so the material being ground does not become full of bits of grit. *Millstone grit* is the name given to a number of coarse-grained Carboniferous Age sandstones in the north of England. The name derives from the use of this stone in watermills and windmills.

BOW AND ARROW

— *c.*8000 BCE —

MESOLITHIC MAN, HAMBURG, GERMANY

Until the widespread adoption of firearms in the 16th and 17th centuries, this was man's most important weapon for hunting and warfare. Before the development of agriculture and herding animals, prehistoric man needed to devise efficient ways of both defending himself from wild beasts, and of killing them for food. Hunters began with missiles that they threw, breaking bones with sticks and stones. Then spears and daggers evolved, with sharp knapped flints being strapped onto a wooden shaft. The next development was the *atlatl*, or spearthrower, which used leverage to project a spear or dart. It consisted of a wooden shaft with a cup or a spur, which could be integrated into the weapon or made separately and attached, in which the butt of the projectile rested. It worked in much the same way that plastic ball throwers are used nowadays to throw tennis balls for dogs to chase. The *atlatl* was held in one hand, gripped near the end farthest from the cup. The dart was thrown by the action of the upper arm and wrist, used in combination with the *atlatl* as an extension of the throwing arm, adding significant force through increased angular momentum. A traditional *atlatl* was a long-range weapon and could achieve speeds of over 90 mph (145 kph). Slingshots were also developed around 10,000 BCE, like the one with which David killed Goliath. It seems that the bow and arrow was developed in Africa and Europe around 20,000 years ago, and it is shown in cave paintings. The earliest recovered arrows, dating from around 8000 BCE, were discovered near Hamburg and were made of pine tipped with flint. They were destroyed in the bombing of Hamburg in the Second World War. The oldest known bow fragments are from Holmegaard in Denmark; they are made of elm and date from 6000 BCE.

THE POWER OF THE LONGBOW

'*In the war against the Welsh, one of the men of arms was struck by an arrow shot at him by a Welshman. It went right through his thigh, high up, where it was protected inside and outside the leg by his iron cuirasses, and then through the skirt of his leather tunic; next it penetrated that part of the saddle which is called the alva or seat; and finally it lodged in his horse, driving so deep that it killed the animal.*' Giraldus Cambrensis, *A Journey Through Wales*, 1191

Archery became increasingly important across the world, with different types of bows and arrows being developed for different purposes. The short composite bow, made up of layers of materials that reacted differently under compression or tension, was invented around 1500 BCE, and enabled the use of mounted archers. The lethal pinnacle of bow-making was the Welsh longbow, which ended the era of mass cavalry charges by knights in armour. Usually archers aimed at the horses, and when the unseated knight lay on the ground, unable to move, they finished him off with a dagger stabbed through chinks in his armour. Until recently, medieval accounts of rates of longbow fire and its killing range and power were thought to be exaggerated because of the strength needed to pull such a bow. However, men were trained to be archers from boys, so had massively developed muscles to enable them to pull the huge bows. Studies of battlefield skeletons have shown disproportionately developed bodies of archers. The right choice of arrowhead could pierce plate armour, and arrows were effective for killing up to 400 yards (365 m) away. An accomplished bowman could release an arrow a second, so a thousand archers could fire a terrifying 300,000 arrows in five minutes.

ÖTZI THE ICEMAN

AROUND 3300 BCE '*Ötzi the Iceman*' was shot with an arrow through the lung. He is Europe's oldest natural human mummy and his body was found in 1991 frozen in ice in a glacier in the Italian Alps, near the present-day border between Austria and Italy. The Iceman had carried an unfinished 6-foot (1.8-m) yew longbow, and evidently leaned it against a rock, where it was found still upright. The stave still had to be shaped, rubbed down and

polished using field horsetail as an abrasive. He also had a copper axe with a yew handle, a flint-bladed knife with an ash handle, and a quiver of 14 arrows with viburnum and dogwood shafts. Two of the arrows, which were broken, were tipped with flint and had fletching (stabilizing fins), while the other 12 were unfinished. The arrows were found in a quiver, which also contained what is probably a bow string, and an antler tool possibly used for sharpening arrow points. It seems that the Iceman had killed two people with the same arrow, and retrieved it each time.

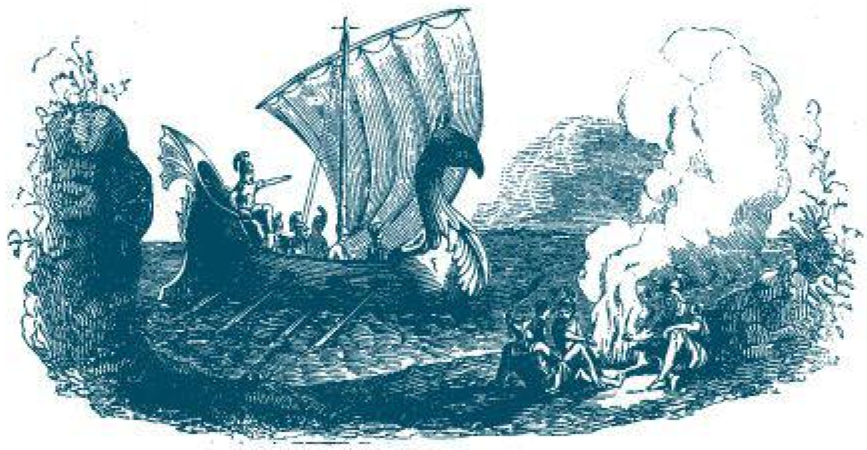
BOAT

—— *c*.7600 BCE ——

USÔUS THE PHOENICIAN, CANAAN

The development of boats and ships enabled the spread of agriculture and civilization from the 'Fertile Crescent' of Phoenicia, Assyria, Mesopotamia and Egypt across the known world. The earliest boats were probably *logboats*, hollowed tree trunks, the earliest of which has been dated to between 8200 and 7600 BCE. A 7000-year-old seagoing boat made from reeds and tar has been found in Kuwait. According to the Greek translation of the Phoenician *Sanchuniathon* (700 BCE?), Usôus cut the branches of a fallen tree, sat aside the log that remained, and paddled through water, thus inventing the boat: '*These persons invented the method of producing fire by rubbing two pieces of wood together, and taught men to employ it. They begat sons of surprising size and stature, whose names were given to the mountains whereof they had obtained possession, viz. Casius, and Libanus, and Antilibanus, and Brathy. From them were produced Memrumus and Hypsuranius. Hypsuranius lived at Tyre, and invented the art of building huts with reeds and rushes and the papyrus plant. He quarrelled with his brother, Usôus, who was the first to make clothing for the body out of the skins of the wild beasts which he slew. On one occasion, when there was a great storm of rain and wind, the trees in the neighbourhood of Tyre so rubbed against each other that they took fire, and the whole forest was burnt; whereupon Usôus took a tree, and having cleared it of its boughs, was the first to venture on the sea in a boat. He also consecrated two pillars to Fire and Wind, and worshipped them, and poured upon them the blood of the animals which he took by hunting. And when the two brothers were*

dead, those who remained alive consecrated rods to their memory, and continued to worship the pillars, and to hold a festival in their honour year by year.'



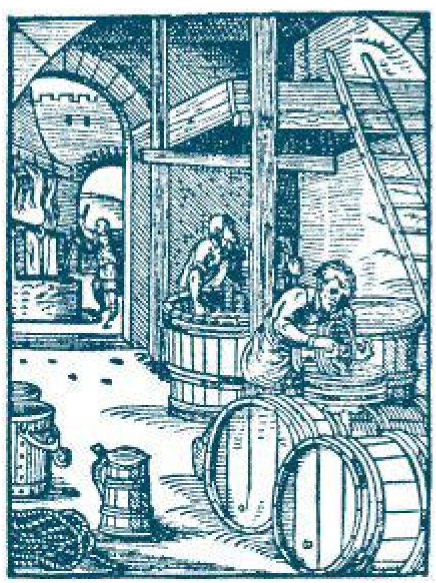
Phoenicia was an ancient civilization in Canaan dating from before 2300 BCE, and it covered most of the western, coastal part of the *fertile crescent*, basically the eastern Mediterranean coastal regions. It now comprises western Jordan, Palestine, Israel and Lebanon. It was the first maritime trading culture, flourishing from 1550 BCE to 300 BCE. The Phoenicians used the galley, a sailing vessel with oars that could be used to head against the wind, and they are credited with the invention of the *bireme*, effectively doubling the number of rowers. They were famed in Classical Greece and Rome as 'traders in purple', referring to their monopoly on the precious purple dye of the *Murex* snail which was reserved for royal clothing. Some claim that the Phoenicians possibly discovered America, and they certainly traded with Cornwall for tin, and with Wales to buy copper and gold. They are also famed for the spread of the alphabet from which all major modern alphabets are derived. The Romans threw all their resources into learning how the Phoenicians and Carthaginians (Carthage was a Phoenician colony) built and navigated boats, and eventually took control of the Mediterranean after bitter resistance.

BEER

—— *c*.6000 BCE ——

SUMER, MESOPOTAMIA

Across the world, beer has been a very important foodstuff, full of calories to sustain hard-working labourers. It was also preferred generally to water, which might be tainted and could cause disease. Its use as a social lubricant came later. If this author is allowed to have one favourite invention from the millennia of recorded history, it has to be beer or ale. The roots of brewing can be traced back to African, Egyptian and Sumerian cultures, and the oldest proven records of brewing are from Sumer, a culture that developed between the Tigris and Euphrates rivers. The area includes southern Mesopotamia and the ancient cities of Babylon and Ur. It is said that the Sumerians discovered the fermentation process by chance. A seal that is around 4000 years old is a Sumerian *Hymn to Ninkasi*, the goddess of brewing. The hymn is also a recipe for making beer. Perhaps originally bread or grain became wet, fermented with wild yeast, and people realized that an inebriating pulp had accidentally resulted. Early accounts, with pictograms of what is recognizably barley, show bread being baked then crumbled into water to make a mash, which is then made into a drink which made people feel '*exhilarated, wonderful and blissful!*' The Sumerians are assumed to be the first civilized culture to brew beer, their 'divine drink' – a gift from the gods.



The Babylonians became the rulers of Mesopotamia after the Sumerian empire collapsed, and they also mastered the art of brewing beer, brewing 20 different types. *Drinking straws* were used to avoid taking in the bitter brewing residue that lay in the bottom of a drinking vessel. King

Hammurabi of Babylon decreed the oldest known collection of laws, one of which established a daily beer ration. The worker received 3.5 pints (2 lit) a day, but high priests received 8.75 pints (5 lit). The Egyptians brewed beer after initially importing it from Babylon. They also used unbaked bread dough for making beer, and added dates to the brew to improve the taste. Across the world different beers were made. Pliny reported the popularity of beer in the Mediterranean area before wine took hold. The oldest proof that beer was brewed on German soil comes from around 800 BCE. Tacitus later wrote: '*To drink, the Teutons have a horrible brew fermented from barley or wheat, a brew which has only a very far removed similarity to wine*'. In the Finnish poetic saga *Kalewala*, 400 verses are devoted to beer but only 200 are needed to describe the creation of the Earth! According to the *Edda*, the Nordic epic, wine was reserved for the gods, beer belonged to mortals and mead (made from honey) was for inhabitants of the realm of the dead.

As the cultivation of barley spread north and west, brewing went with it. As time passed, Christian abbeys, as centres of agriculture, knowledge and science, refined the methods of brewing. However, there was still very little known about the role of yeast in completing fermentation. Beer was considered a valuable (potable) foodstuff and workers were often paid with jugs of beer. It must be remembered that until the 20th century, beer was far less likely to cause illness than water, especially where there were centres of population and where water sources might be contaminated. By the 16th century hops had gained widespread use as a preservative in beer, replacing the previously used bark, herbs or leaves. Perhaps the most widely known event in brewing history was the establishment of German standards for brewers. The first of these regulations was the *Reinheitsgebot* of 1516 – the most famous beer purity law in the world. This pledge of purity states that only four ingredients can be used in the production of beer: water, malted barley, malted wheat and hops. Yeast, though not included in this list, was acceptable, as it was taken for granted as being a key ingredient in the brewing process.

BEER CHANGES PRIMITIVE MAN INTO A HUMAN BEING

FROM PROBABLY the oldest written story, the *Sumerian Epic of Gilgamesh* (*c.*2750–2500 BCE), we learn that not only bread but also beer was very

important. It describes the evolution from primitive man to ‘cultured man’: ‘*Enkidu, a shaggy, unkempt, almost bestial primitive man, who ate grass and could milk wild animals, wanted to test his strength against Gilgamesh, the demigod-like sovereign. Taking no chances, Gilgamesh sent a prostitute to Enkidu to learn of his strengths and weaknesses. Enkidu enjoyed a week with her, during which she taught him of civilization. Enkidu knew not what bread was nor how one ate it. He had also not learned to drink beer. The prostitute opened her mouth and spoke to Enkidu: “Eat the bread now, O Enkidu, as it belongs to life. Drink also beer, as it is the custom of the land”. Enkidu drank seven cups of beer and his heart soared. In this condition he washed himself and became a human being*.’

The next great development occurred in the mid-19th century, through work done by Louis Pasteur, who was the first to propose an explanation of how yeast worked. Shortly thereafter, samples of Bavarian yeast provided the successful identification of a single-cell and strain of the bottom-fermenting lager yeast. German brewers had started to make beer by *lagering* (storing) in 1402. Brewing was not possible in the warm months because wild yeasts prevalent in the warmer weather of summertime would sour the beer. Brewers discovered that brewing in the cold months and storing the beer in caves in the nearby Alps imparted stability to the beer and enhanced it with a cleaner taste, although they did not know why. Today, we know that the reason the beer was clearer and cleaner was due to the fermentation process the beer underwent in the cold, during which the chemicals and bacteria responsible for clouding beer were unable to thrive. They were therefore filtered out of the beer. In 1880, there were approximately 2400 breweries operating in the US embracing many of the classic brewing styles. Today there are only 375 breweries. The change can be traced back to the era of the Volstead Act of 1919 – this ‘Eighteenth Amendment to the Constitution’ ushered in Prohibition. There is a

staggering variety of beers available today, especially in Belgium where there are not only fruit beers, but beers made using the champagne process.

AGRICULTURE

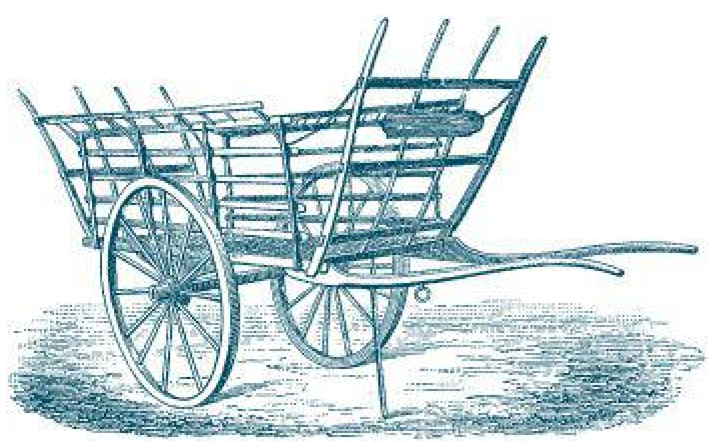
—— *c*.5000 BCE ——

SUMER, SOUTHERN MESOPOTAMIA (MODERN IRAQ)

Agriculture was the stimulus that led humankind to a life of settled civilization rather than nomadic hunter-gathering. The farming of domesticated species of plants and animals created food surpluses allowing people to live together in fixed places like towns and cities. Agriculture began with the planned sowing and harvesting of plants which had previously been gathered in the wild. The earliest agriculture began around 7000 BCE in the *Fertile Crescent* of Egypt, Phoenicia, Assyria and Mesopotamia. The region today comprises Egypt, southeast Turkey, Iraq, Syria, Palestine, Israel, Jordan, Lebanon and western Iran. Independent development of agriculture occurred at different times in India, China, the Sahel zone of Africa and parts of the Americas. The first cultivation in the Old World included the *Neolithic founder crops*, the plant species of emmer wheat, einkorn wheat, hulled barley, peas, lentils, bitter vetch, chick peas and flax. Thus flax (for oil, clothing and cord), three types of cereal and four pulses formed the basis of systematic agriculture. As the Irish political writer Henry Brooke (1706–83) observed: '*In the age of acorns, antecedent to Ceres and the loyal ploughman Triptolemus, a single barleycorn had been of more value to mankind than all the diamonds that glowed in the mines of India*.'

By 6000 BCE, Egyptian agriculture was concentrated on the banks of the Nile, as systems of irrigation had not yet been constructed. Agriculture developed independently in the Far East, with rice rather than wheat being the main crop. Net fishing of rivers, lakes and ocean shores brought in essential protein, and these new methods of farming and fishing sparked a human population boom. Before the development of settled agriculture, there had occurred the domestication of wild aurochs from 6000 BCE (huge wild cattle which became extinct in 1627) and *mouflon* (wild sheep) that were kept as herded cattle and sheep. Farms based on agriculture began the large-scale use of animals for food and skins, and oxen (castrated male cattle) were used for pulling carts and tilling soil.

By 5000 BCE, core agricultural techniques had developed in Sumer, allowing the growth of settlements and eventually cities. Sumerians were the first civilization to practise year-round, large-scale intensive cultivation of land, monocropping (growing a single crop year after year on the same land), organized irrigation and the use of a specialized labour force. The surplus of storable food created by this economy allowed the population to settle in one place, instead of migrating looking for fresh crops and grazing land for their animals. It also allowed for a much greater population density, and in turn required an extensive labour force and the more efficient division of labour. Because of the need to develop a system of recording barter and exchange of crops and animals, Sumer was the site of the earliest development of writing.



WHEEL

— *c*.3500 BCE —

SUMER, SOUTHERN MESOPOTAMIA (MODERN IRAQ)

The wheel has been the most important device in the evolution of transport and technology. It allows heavy objects to be moved easily, through rotating on an axle through its centre. This facilitates movement or transportation while supporting a load, or performing labour with machines. A wheel, together with an axle, lessens friction by facilitating motion by rolling. The earliest evidence of a wheel is a pictograph in Sumer, Mesopotamia, but wheeled vehicles around that time also appeared in the northern Caucasus and central Europe. The earliest depiction of a wheeled vehicle, in this case a wagon with four wheels and two axles, is on a clay pot found in Poland and dated to around 3500–3350 BCE. The oldest known example of a wooden wheel and its axle was found in 2003 in Slovenia, and has been radiocarbon-dated to between 5100 and 5350 years old. Early wheels were simple wooden discs with a hole for the axle. Because of the nature of wood's structure, a horizontal slice of a tree trunk is not suitable as it does not have the structural strength to support weight without collapsing. Rounded pieces of longitudinal boards had to be used.

Between 2200 and 1550 BCE, the spoked wheel was invented, and this allowed the construction of lighter and swifter vehicles. Warfare was transformed with the appearance of horse-driven war chariots. From Mesopotamia and Europe, the adoption of the wheeled vehicle had spread to the Indus Valley by the third millennium BCE, and the spoke-wheeled chariot was seen in both China and Scandinavia by 1200 BCE. War chariots facilitated the rise of Greece and the twin powers of Athens and Sparta. Greek chariot wheels had only four spokes, while the Egyptians had six and the Assyrians eight. About 500 BCE, the Celts invented the wheel hub and the iron rim around the wheel, helping its longevity, and the iron-rimmed wooden-spoked wheel remained in use for two millennia.

Usage of the wheel for long-distance transport was delayed because smooth roads are needed for wheels to be effective. Carrying goods on the back was the preferred method of transportation over surfaces that contained many obstacles. From the 18th century in Europe the development of better *turnpike* (toll) roads, which were maintained in return for tolls, allowed the easy movement of agricultural produce, manufactured goods and stage coaches. The lack of developed roads in Third World

countries prevented general adoption of the wheel for transportation until well into the 20th century. The development of tarmac roads aided the innovation of motor cars from the 1870s, when wire wheels and pneumatic tyres were invented. The invention of the wheel has also been a major factor in many areas of technology, important applications including the water wheel, cogwheel, spinning wheel and astrolabe. The propeller, jet engine and turbine all are descended from the first wheel.

WRITING

—— *c*.3200 BCE ——

SUMER, SOUTHERN MESOPOTAMIA (MODERN IRAQ)

The invention of writing signalled the dawn of the information revolution. This great technological advance allowed news and ideas to be carried to distant places without having to rely upon a messenger's memory. Writing emerged in many different cultures and in numerous locations throughout the ancient world. It was not the creation of any one people. However, the Sumerians of ancient Mesopotamia are credited with inventing the earliest form of writing, which appeared *c*.3500 BCE. The Sumerians recorded trade deals with clay tokens shaped like the goods or animals they had traded, and enclosed the objects in clay envelopes, which they sealed. They marked on the envelope what was inside it. Eventually they realized that there was no need for the tokens, just the description, so in around 3200 BCE the envelopes developed into clay squares marked with symbols recording trade deals. The writings on these tablets are simple pictures, or pictograms, which represent an object or an idea. They progressed from laboriously drawing with a stick to using a pointed reed, developing writing symbols and moving away from pictograms. This was far quicker, as curved lines evolved into wedges or triangles with short straight sides. The letters were written from left to right, but there were no spaces between words. This was the age of *cuneiform* (meaning wedge-shaped) writing, which lasted for three millennia. The laws of Hammurabi of Babylon (d. *c*.1750 BCE) were written in cuneiform writing. In Crete, 3000 years ago, there were three different types of script, and only one, Linear B, has been successfully decoded. Egyptian *hieroglyphs* (sacred

engravings) seem to have been influenced by the Sumerian cuneiform script.

From Egyptian hieroglyphs were developed *abjads* and the Semitic family of scripts. The *abjad* (a type of writing system in which each symbol stands for a consonant) was significantly simpler than the earlier hieroglyphs, and the number of distinct glyphs was reduced tremendously. However, this came at the cost of increased ambiguity. This first consonantal alphabetic writing appeared around 2000 BCE. From around 1500 BCE, the first *abjad* to gain widespread usage was the Phoenician script, consisting of only about two dozen symbols. This made the script easy to learn, and Phoenician seafaring merchants took it across the known world. Phoenician then gave way to a number of new writing systems, including the Greek alphabet from 800 BCE, and Aramaic, a widely used abjad.

ALPHABETS AND ABJADS AND OXEN AND HOUSES

IN AN *abjad* writing system each symbol usually stands for a consonant, with the reader supplying the appropriate vowel. The original name *abğadī* derives from pronouncing the first letters of the alphabet in order. The word alphabet comes from the Latin word *alphabetum*, which in turn derived from the Greek *alpha* and *beta*, the first two letters of the Greek alphabet. Alpha and beta in turn came from the first two letters of the Phoenician alphabet, and meant ox and house (early man’s two most important possessions) respectively.

The Greeks borrowed the Phoenician alphabet and adapted it to their own language. The letters of the Greek alphabet are the same as those of the Phoenician alphabet, and both alphabets are arranged in the same order. The Greek adapter of the Phoenician system also added three letters to the end of the series, called the *supplementals*. The Greeks took letters which did not represent sounds that existed in Greek, and changed them to represent the vowels, the Greek alphabet thus becoming the ancestor of all alphabets in the West.

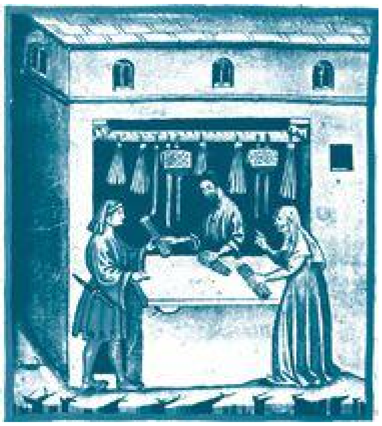
CANDLE

—— *c*.3000 BCE ——

EGYPT AND CRETE

Candles were the main form of lighting for millennia, and were also used as clocks and for religious ceremonies. Candles probably originated when people noticed that when they cooked meat, fat dripped onto the fire and caused it to burn brighter. By soaking reeds in liquid fat, people could burn them for light. The Egyptians and Cretans made candles from beeswax as early as 3000 BCE, and also from rush tapers. Clay candlesticks dating from *c*.400 BCE have been found in Egypt. The candles they held were made by dipping thin cord into molten wax. Early Chinese and Japanese candles were made with wax derived from insects and seeds, moulded in paper tubes. Wax skimmed from boiling cinnamon was the basis of tapers for temple use in India. The earliest known candles that we would recognize today originated in China about 200 BCE, and were made from whale fat. However, candles did not appear in Europe until sometime after 400 BCE, because of the availability of olive oil for burning in oil lamps. The Romans improved the process by inventing the fibre wick. After the fall of the Roman empire, early European candles were made from various forms of natural fats, tallow (fat from cows or sheep) and wax. Tallow was put into the melting pot, and then poured into moulds made of bronze. A trough underneath would catch the excess wax and return it to the melting pot. For the wick, a cord was usually made from the pith of rushes, and suspended from a horizontal rod over the mould when the tallow was poured in. Beeswax and wax candles made from various plant extracts such as

bayberry gradually replaced unpleasant-smelling and smoky tallow candles in churches and in wealthier homes.



In Europe, candles became important parts of religious ceremony, their lighting used to mark holy days and accompany prayer. Since a candle’s burn rate is fairly consistent, they were often used to tell time, and some candles (candle clocks) had hour measurements marked into the wax. These were used in England from 870 CE, and it is said that King Alfred the Great invented them. Some of these candles could act as timers, as a nail was placed at a certain point on the candle and fell off when the appropriate time was reached. By the 18th century, spermaceti (fine wax from the head of the sperm whale) was used to produce a superior candle. Later in the 18th century, colza oil (from a variety of turnip) and rapeseed oil became cheap substitutes.

When paraffin was first distilled in 1830, it became the first choice for candle-making. It was cheap, and produced a reasonably high quality, odourless candle that burned fairly cleanly. Soon after, the discovery of the distillation of kerosene decimated the paraffin candle industry, with cheap oil leading to far more efficient and bright oil lamps. Confusingly, kerosene was also called paraffin, or sometimes paraffin oil in the UK and many other countries. With the advent of cheap whale oil for oil lamps, then kerosene (paraffin) oil lamps, and then gas and electric lighting, candles became less popular. More recently resinbased candles are being used because they burn longer. The wick of modern candles is constructed so that it curves over as it burns, so that the end of the wick protrudes into the hot zone of the flame and is then consumed by fire. Effectively, this is a self-trimming wick.

CANDLES AND SHIPS

A *CHANDLERY* was originally the place in a medieval noble's household or monastery where precious wax and candles were stored. It was looked after by a chandler. Candles were usually made here using beef fat (tallow) and other substances, and in time the term chandler was applied to a seller of candles. Soap was a natural by-product of candle-making, and during the 18th century commercial chandlers sold both soap and candles. As many chandlers became general dealers, in ports they came to supply ships with nautical items, and were for some time called ship-chandleries. Now most ports and busy harbours have a chandler's business nearby.

FISH CANDLE

THE EULACHON is a type of smelt (a small fish) found from Alaska to Oregon. From the first century inidigenous peoples used its oil for lighting. A very simple candle could be made by putting the dried fish on a forked stick and then lighting it.

SWORD

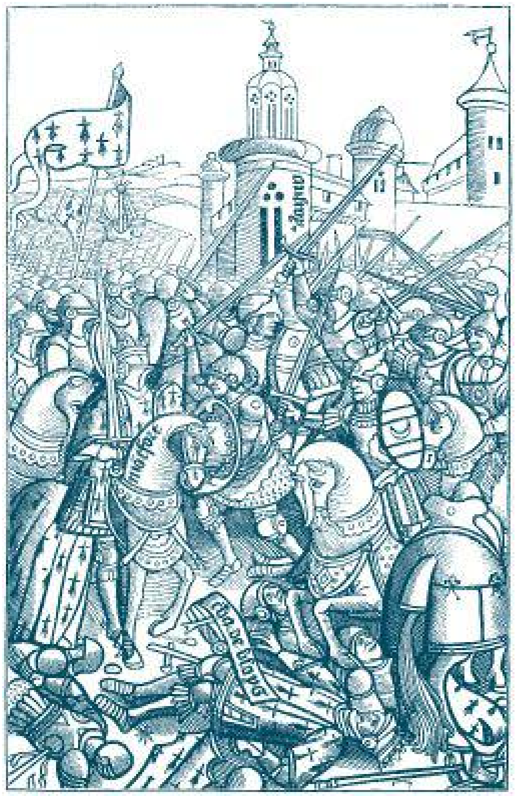
— *c*.3000 BCE —

SUMER, SOUTHERN MESOPOTAMIA (MODERN IRAQ)

For around two millennia these were the favoured weapons in warfare and conquest. Some sword-like weapons dating to 3300 BCE have been found in Anatolia (Turkey), but these are believed to be long daggers. The sword is an adaptation of another tool, the knife, ergonomically adapted for combat. In early history, the dagger was a more common weapon, but in the Bronze Age people learned how to produce longer copper and bronze blades, and the sword became more common. The Sumerian *sappara* was known and used in Egypt as a *khopesh* and in Canaan as a 'sicklesword' from around 3000 BCE. It was about 20 to 24 inches (50 to 60 cm) in length, and designed for hooking an opponent's weapon and disarming him. It evolved from daggers and crescentshaped axes used in warfare. Assyrian infantrymen carried a bow, a dagger and a sappara. The sappara was made

first in arsenic copper, then in tin-bronze in the Bronze Age from around the 17th century BCE. Sword blades longer than 2 feet (60 cm) were rare and not practical until the late Bronze Age, as at longer lengths the tensile strength of bronze tends to decrease radically. Longer blades would easily bend or break. The earliest bronze swords discovered date to 1600 BCE. Copper was alloyed with around 10-12 per cent tin, making the Bronze Age sword strong, but not brittle.

Sword makers started using iron in around 800 BCE, but Iron Age swords remained fairly short, as again they could be easily bent in action. Iron, however, had the advantage of mass-production due to the wider availability of the raw material. Early iron swords were not comparable to later steel blades, as they were not *quench-hardened* (cooled by water), but *work-hardened*, hammered as bronze swords were. Easier production now meant that entire armies could be equipped with metal weapons. The short, flat-bladed Roman *spatha*, later copied in European swords, helped Rome to build its empire. It was not until the development of stronger alloys such as steel, and improved heat treatment that *longswords* became practical for fighting. From the 11th century, swords began to develop elaborate crossguards to protect the hand, and the pommel at the end of the hilt stopped the user’s hand from slipping off the hilt.



Swords were originally designed as cutting weapons, but effective points now became common to counter improvements in armour, especially during the 14th century when chain mail replaced plate armour. Around this time, the *hand and a half* sword, also known as a *bastard sword*, was developed. It had an extended grip, so could be used with either one or two hands. Though the sword did not provide a full two-handed grip, it allowed its wielder to hold a shield or parrying dagger in the other hand, or to use it as a two-handed sword for a more powerful blow. With extreme reach, this longsword had both cutting and thrusting capabilities. Different swords, from sabres to rapiers, were now developed for different purposes. The invention of repeating firearms, which could be quickly reloaded and discharged at a distance, largely brought an end to the age of fighting with a sword. The word sword comes from the Old English *sweard*, meaning to wound or hurt.

HORSE CHOPPING SWORDS

SPECIALIZED ANTI-CAVALRY swords, such as the extremely long *zhanmadao* and the Japanese *zanbatō*, were in use around 1000 years ago.

The name literally means ‘horse chopping sword’. They had a wrapped handle suitable for two-handed use, and were said to have been able to kill the horse and rider with one swing. In the West, similar swords were developed to attack formations of massed pikemen and to cut the legs of galloping horses.

MONEY, BANKING AND CREDIT

—— *c*.3000 BCE *onwards* ——

SUMER, SOUTHERN MESOPOTAMIA (MODERN IRAQ)

The use of money facilitated trading from earliest times. Money is anything that is commonly accepted by a group of people for the exchange of goods, services or resources. Every country has its own system of coins and paper money. In earliest history, people bartered a good or service for another good or service – a fur skin for a salmon, or barley for a spear. However, sometimes we could not agree the value of something, or did not want what the other person was offering in exchange. To solve the problem, humans developed what is called *commodity money*. The first commodity money was livestock or crops, and in some languages even today the word for property or possessions derives from cattle. In the past, salt, tea, tobacco, cattle, grain and seeds were commodities and were therefore once used as money.

Between 9000 and 6000 BCE, cattle were domesticated and crops began to be cultivated. Cattle are probably the oldest of all forms of money, as domestication of animals tended to precede the cultivation of crops. They were still used for that purpose in parts of Africa until recently. Around 3200 BCE, writing was invented in Sumer, and it seems that the probable motivation for its development was for keeping accounts of trading. From 3000 to 2100 the same region developed banking. Sumerians and then Babylonians needed reliable and safe places for the storage of deposits of grain, followed by other goods including cattle, precious metals and even agricultural implements.

By 700 BCE Lydia (now in Turkey) became the first country in the Western world to mint coins. Countries were soon minting their own series of coins with specific values. Metal was used because it was readily available, easy to work with and could be recycled. Since coins were given

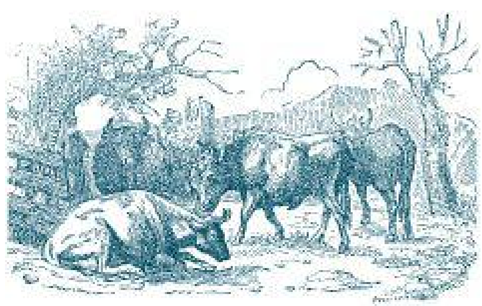
a certain value, it became easier to compare the cost of items people wanted. Between 30 BCE and 14 CE Augustus Caesar issued new gold, silver, brass and copper coins. At the same time as his reform of the Roman monetary system, he introduced three new taxes: a flatrate poll tax, a sales tax and a land tax. Taxation has always gone hand-in-hand with money, and collecting money is far easier than collecting goods or services in payment. The collection of money allowed the huge accumulation of wealth of kings and the great land-owners or nobles.

When the barbarian Anglo-Saxons invaded Christian Britain after the fall of the Roman empire, *c*.435 CE, coins ceased to be used in Britain for 200 years as a medium of exchange, except in Wales, the last refuge of the Britons. Some of the earliest known paper money dates back to China, where its issue became common from about 960 CE onwards. In all countries there have been problems with adulterating coins, and in the reign of England's King Henry I, the quality of the nation's silver currency fell dramatically. In 1124, Henry summoned all the mint masters to his capital at Winchester, and cut their right hands off. The quality of coinage improved in the short term. Over the centuries, banking systems were reformed, money was made more difficult to forge and adulterate, and different forms of credit emerged. With the introduction of paper currency and non-precious coinage, commodity money evolved into *representative money*. This meant that the material that money itself was made of no longer had to be very valuable. To guarantee its value, this representative money was therefore backed by a government or bank's promise to exchange it for a certain amount of silver or gold, whenever required. For example, the old British pound bill or pound sterling was once guaranteed to be redeemable for a pound of sterling silver.

CATTLE AND CHATTEL

THE WORD 'cattle' comes from the Old French/Norman-Picard *chatel*, and when used in English as *chattel* had the meaning of personal property. It reminds us of the days when cows were used as a commodity, and refers to personal belongings, not land. Not only were African slaves in the early colonies recognized as chattels in law, but so were wives across Europe, who were 'owned' as property by their husbands. European noblewomen were also party to *chattel marriages*, although if they brought money or

property with them to the marriage, there were usually contracts involved, and *dower rights* were preserved for the wives. Wives in novelist Thomas Hardy's time were still being bought and sold as chattels, being a commodity of exchange. The English custom of wife-selling began in the late 17th century, when divorce was a practical impossibility for all but the very wealthiest men. After parading his wife with a halter around her neck, arm or waist, a husband would auction her to the highest bidder. Wife-selling provides the backdrop for Hardy's *The Mayor of Casterbridge: The Life and Death of a Man of Character* (1886), in which the central character sells his wife at the beginning of the story. Wife sales in England still appear to have happened in the earliest past of the 20th century, and a woman gave evidence in a Leeds police court in 1913 that her husband had sold her to one of his workmates for £1.



DOUBLE-ENTRY ACCOUNTING 1299–1300

PEOPLE HAD been tracking money (to pay bills, collect taxes) for thousands of years, but trade was becoming too complex by the 1400s, and so the Italians invented double-entry accounting. It happened there because Venice, Genoa, Florence and other Italian city states were central to increasing trade across the Mediterranean to the Middle East and North Africa. Their innovation made banking reliable and enhanced trade and commerce, and Italy quickly became the banking capital and wealthiest country in Europe. It was the 15th-century equivalent of the invention of the Internet and the dotcom boom. For the German sociologist Max Weber, double-entry accounting marked the entry point for capitalism.

The double-entry bookkeeping system is a set of rules for recording financial information, where every transaction or event changes at least two different nominal ledger accounts. The name derives from the fact that financial information used to be recorded using pen and ink in paper books (hence ‘bookkeeping’) and that these books were called journals and ledgers (hence ‘nominal ledger’, etc.). Each transaction was entered twice (thus ‘double-entry’), with one side of the transaction being called a debit and the other a credit. The earliest record is by Antonio Manucci, a Florentine merchant, in accounts he kept in his firm’s branch in Provence in 1299–1300. By the end of the 15th century, the merchant venturers of Venice used the system widely. Benedetto Cotrugli was a citizen of the Dubrovnic Republic, and his 1458 book *Della Mercatura et del Mercante Perfetto*, is credited with being the first to portray the principles and methods of double-entry bookkeeping.

Luca Pacioli (1446/7–1517) was a Franciscan friar who collaborated with Leonardo da Vinci, and taught him mathematics, in Milan. His 1494 *Summa de arithmetica, geometria, proportioni et proportionalità* was a printed mathematics textbook published in Venice, and it contained a detailed description of the double-entry system, allowing others to use it easily. Hence it spread widely across the known world. Pacioli used the accounting equation Equity = Assets minus Liabilities. If the sum of debits for all accounts does not equal the corresponding sum of credits for all accounts, an error must have occurred. He warned that a person should not go to sleep at night until the debits equalled the credits. His ledger had accounts for assets (including receivables and inventories), liabilities, capital, income and expenses, like today’s accounts.

For most of the 19th and 20th centuries, the majority of currencies were based upon representative money through the use of the *Gold Standard*. Representative money has now been replaced by *fiat money* (the Latin ‘fiat’ means ‘let it be done’). Money is now given value by a government fiat or decree, in other words enforceable *legal tender* laws were made. By law the refusal of legal tender money, in favour of some other form of payment, is illegal. However, the high costs of cheque and money payments became a strong motivating factor in the development of electronic payment systems in the USA and abroad. By 1995, over 90 per cent (by value) of all transactions in the United States were made electronically, and the use of credit cards is slowly making money obsolescent for many transactions. Different types of credit are constantly being evolved, and the use of money (in the form of notes or coinage) declining every year.

ABACUS

—— *c.*2700–2300 BCE ——

SUMER (SOUTHERN MESOPOTAMIA, MODERN IRAQ)

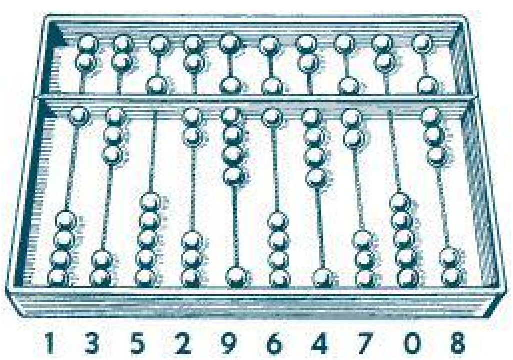
Forbes.com readers, editors and a panel of experts ranked the abacus as ‘*the second most important tool of all time*’, in terms of its impact on human civilization. Before the invention of this first ‘personal calculator’, the best counting tool available was one’s fingers. The abacus, or counting frame, is a calculating tool that is still popular in parts of Asia for carrying out arithmetic. Around 1200 CE the Chinese refined the design, creating the modern, wire-based abacus with a bamboo frame and beads sliding on the wires. However, originally abaci were simply beans or stones moved in grooves in sand, or on tablets of wood, stone or metal. The abacus is one of the first mechanical counting devices and its invention reduced the amount of time necessary to perform complex mathematical operations. This made it an invaluable tool for commerce, science and engineering. The first definite abacus was Sumerian. It was a table of successive columns, which delimited the successive orders of magnitude of their sexagesimal number system. Around 600 BCE the Persians first began to use the abacus, from where their use spread to India, China, Greece and through the Roman empire. Herodotus tells us that the Egyptians manipulated pebbles from right to left, opposite to the Greek left-to-right method. By the fifth century

BCE the Greeks were using a table of wood or marble, pre-set with small counters in wood or metal for mathematical calculations. This development was then used across the Western and Middle Eastern worlds. A white marble slab found on the Greek island of Salamis is dated to 300 BCE, and is the oldest discovered counting board.

The Chinese abacus we see today, known as the *suànpán* (‘counting tray’), usually has a minimum of seven rods or stiff wires. It consists of two parts, one above the other. Each part consists of columns of beads. The lower part usually consists of five beads and the upper part of two beads. The beads in the lower part are assigned values arbitrarily. For example, you may assign the beads in the rightmost column a value of 1. Then you may subsequently assign a value of 10 to the column to its left, and a value of 100 to the column further left and so on. The beads in the upper part are worth five times the value of the beads in the lower part. The hardwood beads are counted by moving them up or down towards the beam. If you move the beads towards the beam, you count their value. If you move them away, you don’t count their value. The *suànpán* can be reset to the starting position instantly by a quick jerk along the horizontal axis to spin all the beads away from the horizontal beam at the centre. Unlike the simple counting board, very efficient *suànpán* techniques have been developed to do multiplication, division, addition, subtraction, square roots and cube roots at high speed.

THE MEANING OF POSITIONAL NOTATION

THE ABACUS uses the concept of one set of objects standing in for objects in another set, and also the concept of a single object standing for a collection of objects. This is known as *positional notation*. This one-for-one correspondence continued up to early calculators, which used the placement of holes in a dial to signify a count, e.g. in a rotary dial telephone. Although these machine often had the number symbol engraved alongside the dial holes, the user did not have to know the relationship between the symbols and their numeric value. The abacus does not actually do the computing, as today's calculators do. It helps people keep track of numbers as they do the computing, and people who are good at using an abacus can often do calculations as quickly as a person who is using a calculator. Not until the 1990s did Russia stop teaching abacus use in primary schools, while it is still taught in China, Japan and other Asian countries.



PYRAMID

—— 2630–2611 BCE ——
IMHOTEP FL.2655–2600 BCE, EGYPT

The Egyptian Imhotep was responsible for the first large-scale architecture of which we know. A commoner by birth, Imhotep's intelligence and determination enabled him to rise to become the most trusted advisor of the pharaoh Djoser. The polymath became chancellor to the pharaoh, and is the first known architect, engineer and physician. The full list of Imhotep's titles is: '*Chancellor of the King of Egypt, Doctor, First in line after the King of Upper Egypt, Administrator of the Great*

Palace, Hereditary nobleman, High Priest of Heliopolis, Builder, Chief Carpenter, Chief Sculptor, and Maker of Vases in Chief.' Imhotep designed and constructed the pharaoh's tomb, the Step Pyramid of Djoser at Saqqara near Memphis in Egypt. Before Djoser, who reigned from 2630–11 BCE, all pharaohs were buried in mastaba tombs. Mastabas were flat-roofed rectangular structures with outward-sloping sides. Manetho, the Egyptian historian, credited Imhotep with inventing the method of a 'stone-dressed' building, although Imhotep was not the first to actually build with stone. Stone walling, flooring, lintels and jambs had all appeared sporadically before Imhotep, but a building of the Step Pyramid's size, made entirely out of stone, had never before been constructed.

The pyramid, originally 203 feet (62 m) high, was the world's tallest structure, with a base of 358 × 410 feet (109 × 125 m), and was clad in polished white limestone. It is the central feature of a massive mortuary complex in a huge courtyard surrounded by a ceremonial structure. This first Egyptian pyramid had six mastabas of decreasing size built on top of one another. Also known as a proto-pyramid, it is thought to be the earliest large-scale cut stone construction. (The oldest known uncut stone pyramid structure dates to 3000 BCE in Caral, Peru). Djoser's step pyramid is a radical departure from previous architecture, and the social implications of such a large and carefully sculpted stone structure are important in the development of civilization. The process of building was far more labour-intensive than it was for previous monuments made of mud-brick, suggesting that the Egyptians had a new level of control of resources, both material and human.

MEDICINE

—— 2630–2611 BCE ——

IMHOTEP FL.2655–2600 BCE, EGYPT

Imhotep's were the first rational and scientific writings on medicine. The 'Edwin Smith Papyrus' of *c*.1600 BCE contains anatomical observations, ailments and cures, and the original source of its knowledge is attributed to Imhotep. More than 90 anatomical terms and 48 cases of injury are described. Each case details the type of the injury, examination of the patient, diagnosis and prognosis. Other papyri are medical texts based on magic, but the Edwin Smith Papyrus presents a rational and scientific approach to medicine in ancient Egypt. It is about 15 feet (4.6 m) long, divided into 17 pages, with hieroglyphic writing on both sides. The majority of the papyrus is concerned with trauma and surgery. On the recto side are recorded 48 cases of injury. The papyrus describes closing wounds with sutures (for wounds of the lip, throat, and shoulder), preventing and curing infection with honey, and stopping bleeding by the application of raw meat. Immobilization is advised for head and spinal cord injuries, as well as other lower body fractures. It contains the first known descriptions of the cranial sutures, the meninges, the external surface of the brain, cerebrospinal fluid and the intracranial pulsations. The procedures of this papyrus demonstrate a level of knowledge of medicines in ancient Egypt that surpassed that of the Western 'father of medicine' Hippocrates, who lived some 2200 years after Imhotep. On account of its practical nature and the types of trauma

investigated, it is believed that the papyrus served as a textbook for treatment of the trauma that resulted from military battles. Imhotep may have also founded the school of medicine in Memphis, which remained famous for 2000 years. Imhotep became a local god at Memphis, where he was glorified for his skills as a physician and a healer. Here he was served by his own priesthood and was considered to be an important intermediary between humans and the gods.

THE FIRST FATHER OF MEDICINE

THE CANADIAN Sir William Osler was called 'the father of modern medicine', but he was clear that Imhotep should be credited as the original 'father of medicine'. He tells us that Imhotep was the: '…*first figure of a physician to stand out clearly from the mists of antiquity. Imhotep diagnosed and treated over 200 diseases, 15 diseases of the abdomen, 11 of the bladder, 10 of the rectum, 29 of the eyes, and 18 of the skin, hair, nails and tongue. Imhotep treated tuberculosis, gallstones, appendicitis, gout and arthritis. He also performed surgery and practised some dentistry. Imhotep extracted medicine from plants. He also knew the position and function of the vital organs and circulation of the blood system*.'

The Encyclopaedia Britannica supports Osler's view: '*The evidence afforded by Egyptian and Greek texts support the view that Imhotep's reputation was very respected in early times. His prestige increased with the lapse of centuries and his temples in Greek times were the centres of medical teachings*.'

PAPYRUS SCROLL

—— 2630–2611 BCE ——
IMHOTEP FL.2655–2600 BCE, EGYPT

Along with the achievements listed above, Imhotep was the high priest of the sun god Ra at Heliopolis, and one of the very few commoners to be accorded divine status after death. Imhotep was also revered as a poet and philosopher, and the centre of his cult was at Memphis. Imhotep was also said to have invented the papyrus scroll (roll), enabling long documents to be written and, more importantly, preserved. (Some of the Dead Sea scrolls were written on papyrus.) Papyrus is a thick paper-like material produced from the pith of the papyrus plant, a wetland sedge formerly abundant in the Nile Delta. It was used as a writing material and also to make boats, mattresses, mats, rope, sandals and baskets. To form the long strip that a papyrus scroll required, a number of papyrus sheets were united, placed so that all the horizontal fibres parallel with the roll's length were on one side and all the vertical fibres on the other. Texts were written on one side, the lines following the fibres, parallel to the long edges of the scroll. Often, papyrus was reused by writing across the fibres on the other side. In Egypt's dry climate, papyrus is stable, as it has a high content of rot-resistant cellulose, and this accounts for the fact that we can still discover legible papyri. The discovery of long papyrus documents has enabled us to study early civilizations.

In the first centuries BCE and CE, papyrus scrolls were gradually replaced as a writing surface by parchment, which was prepared from animal skins. Sheets of parchment were folded to form *quires* from which book-form *codices* were made. Scribes soon adopted the codex form, and in the

Graeco-Roman world it became common to cut sheets from papyrus rolls to form codices. They were an improvement on the papyrus scroll as papyrus was not pliable enough to fold without cracking and a long roll, or scroll, was required to create large texts. Papyrus had the advantage of being relatively cheap and easy to produce, but it was fragile and susceptible to both moisture and excessive dryness. Unless the papyrus was of good quality, the writing surface was irregular, and the range of media that could be used on it was also limited. Papyrus was gradually replaced in Europe by the cheaper locallyproduced products of parchment and calf-skin vellum, which were far more durable in damper climates. The use of papyrus in Egypt continued until it was replaced by more inexpensive paper introduced by Arabs.

THE PATRON OF SCRIBES

JAMES HENRY BREASTED (1865–1935) wrote *A History of Egypt* in 1905, and he remarks of Imhotep: '*In priestly wisdom, in magic, in the formulation of wise proverbs; in medicine and architecture; this remarkable figure of Zoser's reign left so notable a reputation that his name is not forgotten to this day. He was the patron spirit of the later scribes, to whom they regularly poured out a libation from the water-jug of their writing outfit before beginning their work*.'

THE PAPYRUS BOAT

THOR HEYERDAHL (1914–2002) is remembered for his Kon-Tiki expedition when he sailed 4300 miles (6920 km) in a balsa-wood raft from South America to Polynesia in 1947. In 1969 Heyerdahl built a boat from papyrus reed and tried to cross the Atlantic from Morocco. Based on drawings and models from ancient Egypt, his first boat, *Ra*, was built by boat builders from Lake Chad. After a few weeks, *Ra* took on water after its crew made modifications to the vessel that caused it to sag and break apart. The ship was abandoned but, in 1970, he tried again in a similar vessel *Ra II* and this time succeeded in reaching Barbados. Heyerdahl showed that the Atlantic could have been crossed by boat before Columbus, by sailing with the Canary Current.

IRON

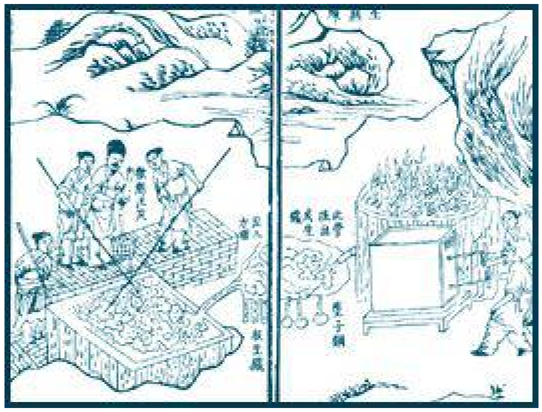
—— *c*.2500 BCE ——

ANATOLIA (TURKEY)

For over three millennia, until it was replaced by cheap steel at the end of the 19th century, iron formed the material basis of human civilization in Europe, Asia and Africa. It has proved the most useful, and therefore the most precious, metal known to man. In the Mesopotamian kingdoms of Chaldea and Assyria, the initial use of iron dates back to perhaps 4000 BCE. One of the earliest smelted iron artefacts is a dagger with an iron blade found in a tomb in Anatolia, dating from 2500 BCE. Because iron was so hard to make compared to copper and bronze, it was fairly scarce before 1500 BCE, when the Hittites of Anatolia discovered newer smelting and smithing techniques. Their empire grew to cover parts of Syria, Lebanon and Mesopotamia, as the nation grew wealthy through trading iron. Although a Bronze Age people, they were the forerunners of the Iron Age manufacturing iron artefacts, and in the 14th century BCE letters to foreign rulers reveal the latter's demand for iron goods. They quickly saw that iron weapons were better and stronger than bronze ones, and kept the secret of making iron for about 400 years, until about 1100 BCE.

Around this time, Mediterranean peoples started to use iron, and from around 1000 BCE until to the present day iron has been the most used metal. Iron is the fourth most abundant element and makes up more than 5 per cent of the Earth's crust. When alloyed with a little carbon, iron is harder, more durable and holds a sharper edge than bronze. When iron ore is heated in a charcoal fire, the iron ore begins to release some of its oxygen, which combines with carbon monoxide to form carbon dioxide. A spongy, porous mass of relatively pure iron is formed, intermixed with bits of charcoal and extraneous matter liberated from the ore, known as *slag*. The separation of slag from the iron was later facilitated by the addition of flux, such as crushed seashells or limestone. The formation of this *bloom* of iron was as far as the blacksmith could go. He would remove this pasty mass from the furnace and hammer it on an anvil to drive out the cinders and slag, and to compact the metallic particles. This was known as *wrought iron* (wrought simply means worked, i.e. hammered) and it contained generally from 0.02–0.08 per cent of carbon (absorbed from the charcoal), just enough to

make the metal both tough and malleable. Wrought iron was the most commonly produced metal through most of the Iron Age.



At very high temperatures (rare except in a blast furnace), the iron begins to absorb carbon rapidly, and the iron starts to melt, since the higher carbon content lowers its melting point. The result is *cast iron*, which contains from 3–4.5 per cent carbon. To cast means to pour into a mould, hence the name cast iron. The high proportion of carbon makes cast iron hard and brittle. It is liable to crack or shatter under a heavy blow, and cannot be *forged* (heated and shaped by hammer blows) at any temperature. However, by the late Middle Ages, European iron-makers developed the blast furnace, a tall chimney-like structure in which combustion was intensified by a blast of air pumped through alternating layers of charcoal, flux and iron ore. Molten cast iron ran directly from the base of the blast furnace into a sand trough, which fed a number of smaller lateral troughs. The configuration resembled a sow suckling a litter of piglets, and cast iron produced in this way thus came to be called *pig iron*. Casting is also called founding and is done in a foundry. Iron could now be cast directly into moulds at the blast furnace base or remelted from pig iron to make cast-iron stoves, pots, pans, fire-backs, cannon, cannonballs or bells.

Iron-makers also learned how to transform cast pig iron into the more useful wrought iron by oxidizing excess carbon out of the pig iron in a charcoal furnace called a *finery*. After 1784, pig iron was refined in a *puddling* furnace, developed by Henry Cort. The puddling furnace required the stirring of the molten metal, kept separate from the charcoal fire, through an aperture by a highly skilled craftsman called a *puddler*. This exposed the metal evenly to the heat and combustion gases in the furnace,

so that the carbon could be oxidized out. As the carbon content decreases, the melting point rises, causing semi-solid bits of iron to appear in the liquid mass. The puddler would gather these in a single mass and work them under a forge hammer. Then the hot wrought iron would be run through rollers (in rolling mills) to form flat iron sheets or rails. Slitting mills cut wrought-iron sheets into narrow strips for making nails.

THE ART OF THE PUDDLER

'*THE PUDDLING furnace remained the bottleneck of the industry. Only men of remarkable strength and endurance could stand up to the heat for hours, turn and stir the thick porridge of liquescent metal, and draw off the blobs of pasty wrought iron. The puddlers were the aristocracy of the proletariat, proud, clannish, set apart by sweat and blood. Few of them lived past forty. Numerous efforts were made to mechanize the puddling furnace – in vain. Machines could be made to stir the bath, but only the human eye and touch could separate out the solidifying decarburized metal. The size of the furnace and productivity gains were limited accordingly*.' David Landes, *The Cambridge Economic History of Europe*, Vol. VI, Part I, 1966

LATHE

— *c*.2500 BCE —
GREECE, EGYPT AND ASSYRIA (MESOPOTAMIA)

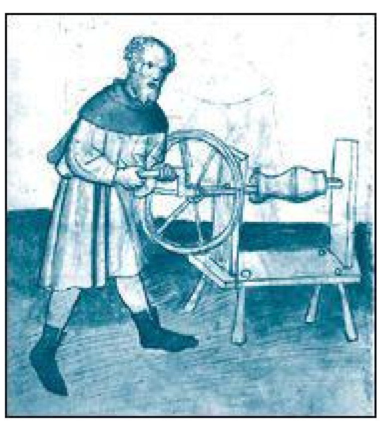
Lathes have been essential in manufacturing for three millennia. These tools are used to fabricate items, by the selective removal of material. In their simplest form, a piece of wood is spun around a fixed axis, and pieces of the material are chipped off with a blade. The lathe dates at least to ancient Egypt and was known and used in Assyria and Greece. Marble vases made with lathes have been found on several Aegean islands, dating from around 2000 BCE. Around 1300 BCE Egyptians first developed a two-person lathe. One person would turn the woodwork piece with a rope while the other used a sharp tool to cut shapes in the wood. The Roman improved the Egyptian design with the addition of a turning bow. The bow string was wrapped around the lathe's central axis and a craftsman's assistant would work the bow back and forth to spin the lathe. In 1480, Leonardo da Vinci

designed a lathe powered by foot treadle, which allowed for constant rotation, freeing both the craftsman's hands to hold the wood-turning tools. The pedal was usually connected to a pole, often a straight-grained sapling. The system today is called the *spring pole* lathe. Spring pole lathes were in common use into the early 20th century in the furniture industry.

During the Industrial Revolution, mechanized power generated by water wheels or steam engines was transmitted to the lathe via line shafting, allowing faster and easier work. Metalworking lathes evolved into heavier machines with thicker, more rigid parts. Between the late 19th and mid-20th centuries, individual electric motors at each lathe replaced line shafting as the power source. Beginning in the 1950s, servomechanisms were applied to the control of lathes and other machine tools via numerical control. These were then coupled with computers to yield computerized numerical control (CNC). Today manually controlled and CNC lathes coexist in the manufacturing industries, used for cutting, sanding, knurling, drilling or deformation. They are used in woodworking, metal spinning, metalworking, glassworking and pottery. The potter's wheel is a type of lathe.

THE FIRST WOODEN DISH

A FLAT wooden dish which stood on wooden legs was found in a pit grave at Mycenae, north of Athens and dated 1400–1100 BCE. The dish has low side walls with a bead running around the top, which is typical of turned work. There is also a hole in the centre, which has been plugged. This suggests that it could have been turned on a mandrel held between centres in a lathe.



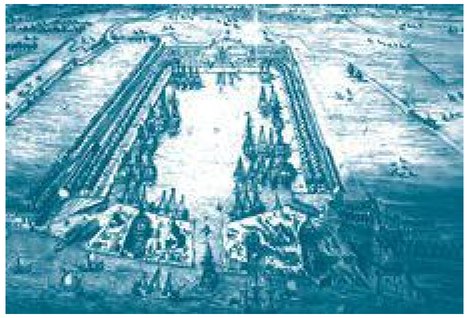
DOCK

— *c*.2400 BCE —

LOTHAL, THE INDUS VALLEY, GUJARAT, INDIA

Docks are enclosed areas of water, equipped to berth, build, load, unload and service ships. Until their adoption, ships were anchored at sea, and goods were ferried to and from shore by small boats. Discovered in 1954, Lothal was excavated and the world's earliest known dock was discovered. It connected the city to an ancient course of the Sabarmati river on an important trade route. Because of the loam deposited by persistent floods, the mud-brick dock walls were preserved after the great deluge of *c*.1900 BCE. Standing high walls are absent because of erosion and brick robbery, but there were evidently wharfs and warehouses. The inlet channel and riverbed have been similarly covered up by silt. Oceanographers have concluded that the builders had great knowledge relating to tides to be able to build such a dock on the ever-shifting course of the river, as well as impressive expertise in hydrography and maritime engineering.

Lothal was a *wet dock* (or impounded dock) in which the water is impounded by dock gates or by a lock, allowing ships to remain afloat at low tide in places with high tidal ranges. The Howland Great Dock on the River Thames was the world's first enclosed wet dock with lock gates to maintain a constant water level, irrespective of tidal conditions. It was built in 1703. There were no unloading facilities. The world's first commercial enclosed wet dock, with quays and unloading warehouses, was Steers Dock at Liverpool (1715). This reduced the waiting times of ships, giving quick turnarounds and greatly improving the throughput of cargo. A dry dock also has dock gates, but can be emptied of water to allow investigation and maintenance of the submerged parts of ships. They seem to have first existed in Egypt around 200 BCE. The first early modern European dry dock, and also the oldest surviving dry dock still in use, was commissioned by Henry VII at Portsmouth in 1495.



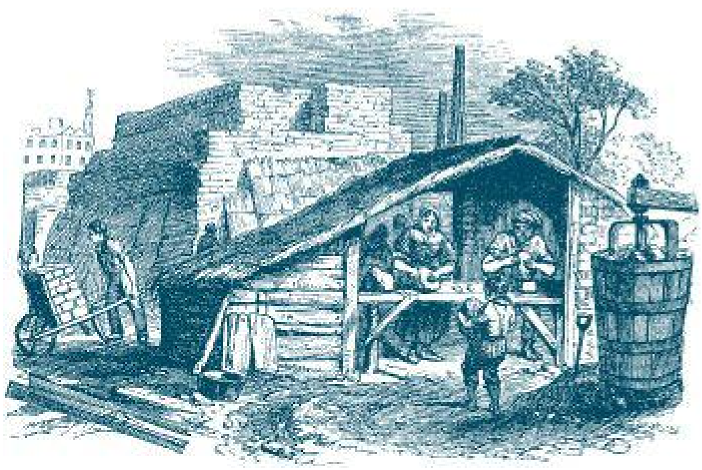
FIRED (CERAMIC) BRICK AND TILE

—— *c*.1800 BCE ——
XI'AN, CHINA

Bricks and tiles were the staple building products across the world where there was a shortage of local stone. They were first produced in a sun-dried form around 7500 BCE. These *mud bricks* were one of the first building materials. It is thought that after floods on rivers such as the Tigris, Euphrates and Nile, the deposited mud and silt formed hard cakes that could be shaped into the building blocks for the walls of crude huts. Early dried-mud brick buildings have found in Anatolia (Turkey), Syria and in the upper Tigris Valley (Turkey and Iraq). Recent findings of mud bricks, dated between 7000 and 6395 BCE, come from Catal Höyük (Turkey) and Jericho (Palestine). The first known arch of sun-dried brick was built in Ur, Mesopotamia, around 4000 BCE. The mortar used to bind the sun-dried bricks together was mud until this time, but the Ur arch is described as using *bitumen slime* as mortar. At some point it was found that mud bricks, when heated in fires, acquired far greater strength and durability. Bricks began being fired with varying results. In China, early traces of fired mud bricks were found in a ruin site in Xi'an, southwest of Beijing in 2009, and dated to *c*.3800 years ago. The bricks are the earliest so far discovered that were made by a firing process. The burnt mud brick is the forerunner of an enormous range of structural clay products used today. Bricks and tiles are now fired in a kiln, or oven, to produce strength, hardness and heat resistance.

The ziggurat at Ur was an example of early monumental brickwork built of sun-dried brick, but its steps were replaced in about 1500 BCE by fired brick. Potters at Ur had developed the closed kiln, in which heat could be controlled to produce uniform strong bricks. *Enamelling* (glazing) of brick

and tile was developed by the Babylonians and Assyrians as early as 600 BCE, using pottery techniques. The Dome of the Rock in Jerusalem and the great mosques in Iran's Tehran and Isfahan use glazed tiles as mosaics. As civilization spread from the Middle East, so did the use of bricks. The Egyptians used them extensively, and the Great Wall of China (begun around 220 BCE) uses both sun-dried and fired bricks. The amazing Roman Pantheon (123 CE) has a brick and concrete dome. Across the empire, Roman legions operated kilns and introduced fired clay bricks, usually stamped with the mark of the legion responsible. For example, a terminating tile from the barracks roof of the XX Roman legionary fort at Chester is stamped with its symbol, the wild boar and the figure XX.



Europe has probably exploited brick as a building and architectural element more than any other continent. It was important in combating the disastrous fires that chronically affected medieval cities with their wood-framed and wood-panelled house that were built close together. Thus, after the Great Fire of 1666, London changed from being a city built of wood to become one made principally of brick. Transportation in bulk of building materials such as bricks over long distances was rare before the age of canals, railways, roads and heavy goods vehicles. Before this time bricks were generally produced close to their point of intended use, and different styles and colours of bricks can be seen on older houses that are representative of their local area. Bricks were now often used for reasons of speed and economy, even in areas where local stone was available. The buildings of the Industrial Revolution in Britain were largely constructed of brick and timber owing to the accelerating demand.

Basically, the process of brick-making has not changed since the first fired bricks were produced. The phases used then are used today: securing the clay, beneficiation (extracting the useful part), mixing and forming, drying, firing and cooling. ‘True’ bricks are ceramic, created by the action of heat and cooling. Clay is the most common material used, with modern clay bricks formed in one of three processes – soft mud, dry press or extruded. Normally brick contains by weight: 50–60 per cent silica (sand); 20–30 per cent alumina (clay); 5–6 per cent iron oxide; 2–5 per cent lime and under 1 per cent magnesium oxide (magnesia). In general, the size of a brick is determined by what one man can easily handle, but every nation’s brick-making industry produces a range of sizes that may run into the hundreds. The majority of bricks for most construction purposes have dimensions of 2¼ × 3¾ × 8 inches (5.7 × 9.5 × 20 cm).

PLASTIC SURGERY

—— *c*.550 BCE ——

SUSHRUTA, SIXTH CENTURY BCE, VARANASI, INDIA

Sushruta was an Indian believed to have lived in the sixth century BCE, although his dates are disputed. He was the author of the Sanskrit text *Sushruta Samhita* (‘Sushruta’s Compendium’). In this, he describes 121 surgical instruments to be used in 42 different surgical processes, and more than 300 kinds of operations. He also classifies 1120 illnesses, and human surgery in eight categories. Operations are described for amputations, haemorrhoids, hernia repair, eye surgery and Caesarean section. Sushrutha is also the father of plastic surgery and cosmetic surgery. In the phrase *plastic surgery*, the term plastic comes from the Greek word for sculpting, or the *art of modelling*. Sushruta lays down the basic principles of plastic surgery by advocating a proper physiotherapy before the operation and describes various methods or different types of defects. They include: release of skin for covering small blemishes; rotation of skin flaps to make up for partial loss; and pedicle flaps for covering complete loss of skin from an area. Sushruta’s surgical instruments and operations were copied across the known world.

Susrutha reconstructed noses that had been amputated as a punishment for crimes, with his technique of forehead flap *rhinoplasty* (repairing the

disfigured nose with a flap of skin from the forehead. This is practised almost unchanged in technique to this day. Sushruta's rhinoplasty procedure was observed in India by a British surgeon in 1793 and his observations were published in London the following year, thus changing the course of plastic surgery in Europe. The *Sushrutha Samhita* contains the first known description of several operations, including the uniting of bowel, the removal of the prostate gland, the removal of cataract lenses and the draining of abscesses. Sushruta describes the need for, and method of, conducting dissections on human cadavers to gain knowledge of anatomy. Quartered sacrificial animals were used to study different kinds of anatomy. Sushruta was the first surgeon to advocate practising surgical skills on inanimate objects, such as watermelons, clay pots and reeds.

The text is long, running over 1700 pages in English translation. Sushruta details about 650 drugs, of animal, plant and mineral origin. Other chapters make clear the high value that he put on the well-being of children, and on that of expectant mothers. Sushruta's coverage of *toxicology* (the study of poisons) is extensive, and he goes into great detail regarding symptoms, first-aid measures and long-term treatment, as well as classification of poisons and methods of poisoning. Sushruta extols the benefits of clean living, pure thinking, good habits and regular exercise, and special diets and drug preparations. Sushruta explains the origins of disease as imbalances of vital humours that occur either individually or in combination, and that originate from within the body or outside of it, or for no known reason. The *Sushruta Samhita* was translated into Arabic and later into Persian. These translations helped to spread his works far beyond India.

CHAPTER 2

THE GENIUS OF THE CLASSICAL WORLD

INDESTRUCTIBILITY OF ATOMS

EXISTENCE OF GALAXIES AND THE SOLAR SYSTEM PERMANENCE OF MATTER UNDERSTANDING OF ECLIPSES

—— *c*.460 BCE ——

ANAXAGORAS OF CLAZOMENAE *c*.500–428 BCE, IONIA (MODERN TURKEY)

Anaxagoras was the first writer to declare the indestructibility of atoms, to postulate the existence of galaxies and to understand eclipses. Born in Lydia, now part of Turkey, this Ionian Greek introduced philosophy into Athens when he moved there around 480 BCE. As to the structure of matter, Anaxagoras postulated an infinite number of elements, or basic building blocks. He believed that in the physical world everything contains a portion of everything else. He concluded that in order for the food that an animal eats to turn into bone, hair, flesh, etc., it must already contain all of those constituents within it. Anaxagoras noted '*The Greeks are wrong to recognize coming into being and perishing; for nothing comes into being nor perishes, but is rather compounded or dissolved from things that are. So they would be right to call coming into being composition and perishing dissolution.*' Today we know that every atom in existence on Earth has always existed since its creation inside a star, verifying Anaxagoras's claims.

He maintained that the Sun was not a golden chariot steered across the sky by a distant god, but instead a red-hot mass of metal or stone. He said that the Moon was a cold mass of stone, and was the first to teach that it merely reflected the Sun's rays and did not itself emit light. In about 450

BCE Anaxagoras was imprisoned for these beliefs. He was also the first to explain correctly the reason for eclipses of the Sun and Moon. Anaxagoras also believed that the world was created through the rotary motion of a spiral, where initially all mass was united in the centre, then flung out by centrifugal force to create celestial bodies, elements and substances. Galaxies could not be observed at this time as the Greeks did not possess telescopes, so some believe that his thoughts are derived from the wisdom of a previous civilization. (Telescopes are understood to have been first invented in Holland in the early 17th century). His teachings led to charges of impiety against the gods, and Anaxagoras was sentenced to death in Athens, which was then commuted to exile for the rest of his life.

‘THE THINGS ON HIGH’

‘*THE CITIZENS of Athens … passed a law permitting impeachment of those who did not practise religion and taught theories about “the things on high”. Under this law they persecuted Anaxagoras, who was accused of teaching that the sun was a red-hot stone and the moon was earth.*’ Bertrand Russell, *History of Western Philosophy*, 1961

FOUR ELEMENTS THEORY

CENTRIFUGAL FORCE SURVIVAL OF THE FITTEST SPEED OF LIGHT

—— *c*.450 BCE ——

EMPEDOCLES OF ACRAGAS *c*.490–*c*.430 BCE, AGRIGENTUM, SICILY

The ‘four elements theory’ of Empedocles influenced Western thought in one form or another almost until the 18th century. Born in the Greek colony at Acragas (Agrigentum) in Sicily, Empedocles was a philosopher, physician and poet who followed the ideas of Pythagoras. Empedocles was the last Greek philosopher to write in verse, and his foresight and influence are astounding.

Over 2000 years before Einstein, he stated that light takes time to travel, but so little time that we cannot observe it. He also discovered centrifugal force, whirling a cup of water around on a piece of string to prove his

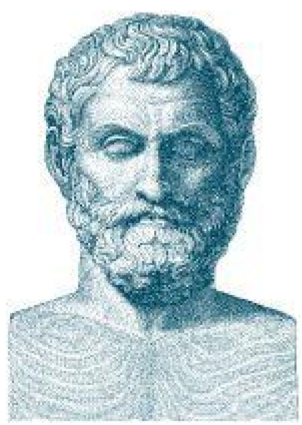
theory. In addition, Empedocles conceived a theory of evolution which included the idea of '*the survival of the fittest*'. He thought that in prehistoric times strange creatures had populated the world, of which only certain forms had survived. Like Anaxagoras, he believed that matter was immutable, always in existence. Empedocles also showed that air existed and was not an empty space, using a simple experiment. He was remarkably ahead of his time, stating that the Moon shone by reflected light and that solar eclipses are caused by the interposition of the Moon, again like Anaxagoras. Aristotle is said to have considered Empedocles the 'inventor of rhetoric', and the Roman physician Galen regarded him as the founder of the science of medicine in Italy. Empedocles wrote that motion and change actually exist, and that at the same time reality is fundamentally changeless: '*And in addition to them* [elements] *nothing comes into being or ceases.*' He was the first philosopher to propose the four *primordial elements* of earth, air, fire and water. Heraclitus had argued that fire was the origin of everything, to Pythagoras it was water, and for Anaximenses the primordial element had been air. Empedocles' proposition that '*all is composed of the four roots* [elements]' theory is extremely important in the development of science since it was adopted by Plato and Aristotle. He tried to explain the multitudinous complexity of the world as being the consequence of a small number of simple underlying properties. We are still in search of simple mathematics that will explain the complex phenomena that surround us.

THE SPEED OF LIGHT

EMPEDOCLES correctly concluded that light had a finite velocity through his power of reasoning, not scientific observation: '*Empedocles says that the light from the Sun arrives first in the intervening space before it comes to the eye, or reaches the Earth. This might plausibly seem to be the case. For whatever is moved through space, is moved from one place to another; hence, there must be a corresponding interval of time also in which it is moved from the one place to the other. But any given time is divisible into parts; so that we should assume a time when the sun's ray was not as yet seen, but was still travelling in the middle space.*' Aristotle (384–322 BCE), *De Sensu et de Memoria*

FOUR ELEMENTS

THALES OF MILETUS (*c*.624–*c*.546 BCE) tried to explain natural phenomena without reference to mythology. He was the first person to study electricity and is the earliest person to use deductive reasoning applied to geometry. He believed that the origin of the world was water. Anaximander of Miletus (*c*.610–*c*.546 BCE) succeeded Thales as head of the Milesian school of philosophers. Anaximander introduced the abstract *apeiron* (infinite) as an origin of the universe, something unlimited in its source that could create without experiencing decay, so that genesis would never stop. Anaximander understood the beginning or first principle to be an endless, unlimited primordial mass (*apeiron*), subject to neither old age nor decay, that perpetually yielded fresh materials from which everything we perceive is derived. Anaximander argued that water cannot embrace all of the opposites found in nature so he reasoned that it needed *apeiron* to form *arche*, the underlying material of the world. Anaximenes of Miletus (*c*.585–*c*.528 BCE) was a friend or student of Anaximander, but he asserted that air was the fundamental substance of which all things were made. To Heraclitus of Ephesus (*c*.535–*c*.475 BCE) fire was the most fundamental element, giving rise to the other elements and all things. Empedocles compounded their theories into a single whole philosophical system.



ATOMIC THEORY, THE EARTH IS ROUND AND MANY WORLDS

— *c*.430 BCE —

DEMOCRITUS OF ABDERA *c*.460–*c*.370 BCE, THRACE, GREECE

Democritus is called 'the father of modern science', and he famously proclaimed '*I would rather discover one scientific fact than be King of Persia.*' However, his ideas were not accepted for more than 2000 years. Democritus wrote books on mathematics, geometry and nature, but is best remembered for expanding the atomic theory of his teachers Leucippus and Anaxagoras. In turn, Democritus influenced Epicurus. Democritus and Leucippus believed that nothing could be divided ad infinitum. Democritus wrote that everything is composed of extremely small particles, which he called *atoms*. These are physically, but not geometrically, indivisible. These atoms are indestructible, so are eternal, and between atoms there is empty space. Atoms are constantly in motion, and there is an infinite number of different kinds of atoms, varying in shape, size and properties. Nature only exists of two things – atoms and the void around them. Democritus denied that the motion of atoms is impelled in any way. Instead he held that atoms move at random, as in the modern kinetic theory of gases. He illustrated the movement of atoms with an observation he made in nature, comparing it to the movement of dust particles in a sunbeam when there is no wind. When atoms collide in space, sometimes they deflect off each other, but sometimes their shapes match in a way that allows them to form interlocked clusters that we can perceive, e.g. fire or water. Predecessors had argued that the origin of matter was water, air, fire, earth, or a combination of all four elements. Democritus and the atomist school of philosophers reasoned that these four elements are not primordial substances, but are composed of atoms like everything else.

FIRST PRINCIPLES

'*THE FIRST principles of the universe are atoms and empty space. Everything else is merely thought to exist. The worlds are unlimited. They come into being and perish. Nothing can come into being from that which is not, nor pass away into that which is not. Further, the atoms are unlimited in size and number, and they are borne along in the whole universe in a vortex, and thereby generate all composite things – fire, water, air, earth. For even these are conglomerations of given atoms. And it is because of their solidarity that these atoms are impassive and unalterable. The sun and the moon have been composed of such smooth and spherical masses* [i.e. atoms], *and so also the soul, which is identical with reason.*' Democritus

quoted in Diogenes Laërtius' *Lives and Opinions of Ancient Philosophers IX 44*, 2nd century CE

Democritus believed that the Earth was round, and wrote that originally the universe was composed of nothing but tiny atoms churning in chaos, until they collided together to form larger units, including the Earth and everything on it. He reasoned that there were many worlds, some growing and some decaying. Some would have no sun or moon and some would have several. Every planet would have a beginning and an end, and a world could be destroyed by collision with another celestial object. Not until the 20th century did we understand that atoms were indeed particles with a tiny positively charged nucleus surrounded by clouds of electrons. Democritus's fully mechanistic view of nature, in which every material phenomenon is seen as a product of atomic collisions, remains valid today. His theory had no place for the intervention of gods in the workings of the world, and he even held that the mind and soul are formed by the movement of atoms. His is an amazing legacy, the forerunner of contemporary atomic theory by two millennia.

BELIEF THAT ILLNESSES HAVE NATURAL, NOT SUPERNATURAL, CAUSES

—— *c*.420 BCE ——

HIPPOCRATES OF KOS *c*.460–*c*.377 BCE, KOS, GREECE

The greatest physician of the Western world founded a medical school on Kos and travelled across Greece preaching his ideas. As 'the father of

medicine', Hippocrates has influenced medical treatment for over two millennia. He developed an 'oath' of medical ethics to be observed by physicians, and his *Hippocratic Oath* is still taken by doctors today as they begin their medical practice. Hippocrates based his practice on practical observation and on the study of the human body, holding that all illnesses had a rational physical explanation. The prevailing belief at the time was that illnesses were caused by evil spirits and the gods, and sick people were carried to the temple of Aesculapius, the god of medicine and healing. However, Hippocrates explained '*Men think epilepsy divine, merely because they do not understand it. But if they called everything divine which they do not understand, why, there would be no end of divine things.*' Hippocrates and other Greek doctors believed that the work done by a doctor should be kept separate from the work done by a priest, and understood that observation of a patient was a vital aspect of medical care. Ancient Greek doctors did examine their patients but Hippocrates wanted a more systematic period of observation and the recording of what was observed. Today, we would call this 'clinical observation'. He seems to have been the first physician to believe that the body must be treated as a whole and not as a series of parts. He wrote: '*Cure sometimes, treat often, comfort always.*'

'ARS LONGA, VITA BREVIS'

ANCIENT GREEK medical knowledge is contained in what is known as the *Hippocratic Collection* (or *Writings*), a collection of 60 medical books of which Hippocrates wrote just some, and which formed the basis of medical practice across Europe for two millennia. Among the works can be found the famous proverb '*Ars longa, vita brevis*' ('Art is long, Life is short'). However, in context the aphorism can be interpreted somewhat differently: '*Life is short, the Art* [of medicine] *long, opportunity fleeting, experience treacherous, and judgement difficult. The physician must be ready, not only to do his duty himself, but also to secure the co-operation of the patient, of the attendants and of externals.*'

Hippocrates described symptoms which others might recognize, being the first physician to record the symptoms of pneumonia accurately. In the text *On Epidemics* doctors were told to note specific symptoms, and what was observed, on a day-to-day basis. By doing this they could produce a natural history of an illness. Hippocrates and other doctors believed that by doing this they could forecast the development of the illness in the future. Hippocrates believed in the natural healing process of rest, a good diet, fresh air and cleanliness, noting that some individuals were better able to cope with their disease and illness than others. As regards modern diets, we find common sense in Hippocrates: '*Even when all is known, the care of a man is not yet complete, because eating alone will not keep a man well; he must also take exercise. For food and exercise, while possessing opposite qualities, yet work together to produce health.*' He was also the first physician to argue that thoughts, ideas and feelings come from the brain and not the heart as others of his time believed.

PIKE (SARISSA), PHALANX

—— 359 BCE ——

PHILIP II OF MACEDON 382–336 BCE, MACEDON, GREECE

The pike and phalanx enabled Philip II’s son Alexander to conquer the known world. The European cornel tree, *Cornus mas*, is a type of dogwood that was used from the seventh century BCE by Greek craftsman as the favoured hard wood to make spears, javelins and bows. It was used to make the heavy *sarissa* (long pike), which weighed around 12 pounds (5.4 kg) for a 15-foot (4.5-m) pike, and almost 14 pounds (6.3 kg) for an 18-foot (5.5-m) pike. The pike’s sharp iron head was shaped like a leaf, and its bronze butt-spike allowed it to be anchored to the ground, allowing a mass of pikes to halt charges by enemy soldiers or cavalry. The butt-spike also helped to balance the spear, making it easier to wield, and could be used as a back-up point if the iron head broke. Both hands were needed to use it, allowing only a small shield hung from the neck to protect the left shoulder. Other soldiers, with shorter weapons, could not combat a tightly packed phalanx of sarissa-bearers. This tight formation created a ‘wall of pikes’ and the length of the pikes meant that five rows of them could project in front of the front rank of the phalanx. The invention of the sarissa and the phalanx formation is credited to Philip II in 359 BCE, when he defeated 3000 Athenian hoplites at the start of his reign. He mercilessly drilled his troops to manoeuvre in phalanxes so that they were virtually invulnerable from the front, except if they came up against another better-trained or stronger phalanx. Generally the phalanx could only be defeated by outflanking it or breaking its formation. By the time he was assassinated, Philip’s small kingdom had conquered Greece and Thrace.

THE END OF THE SARISSA

PHILIP’S SON, Alexander the Great, conquered Egypt, Persia and northwest India, making effective use of the formation of phalanxes supported by cavalry and javelin-throwers. After Alexander’s death, his

generals stopped protecting the phalanxes with cavalry and light-armed mobile troops, and as a result, flank attacks destroyed them. The sarissa was later replaced by variations of the sword as the main battle weapon.

SCIENTIFIC METHOD

— *c*.350 BCE —

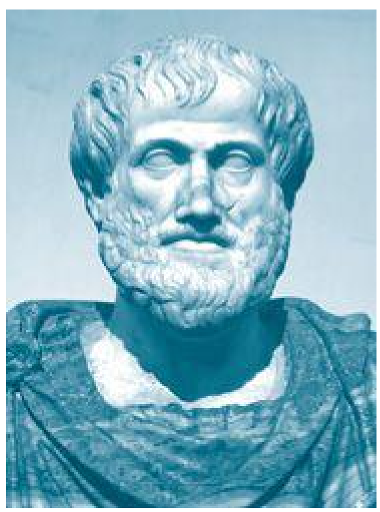
ARISTOTLE OF STAGEIRA 384–322 BCE, GREECE

This 'founder of science' pioneered the studies of botany, zoology, anatomy, physiology and embryology. Around 350 BCE, Aristotle left Macedonia to study under the ageing Plato at his Academy in Athens. When Plato died, Aristotle travelled to the Macedonian capital, Pella, in 342 to tutor the 13-year-old Prince Alexander, who was to become Alexander the Great. Later Aristotle returned to Athens to open his own school, the Lyceum, which was in competition with the Platonic Academy for hundreds of years. Aristotle used Socratic logic to try and explain the natural world, becoming the father of today's scientific method. He tried to impose man-made order on natural phenomena, classifying animals and plants in a way that would make sense to succeeding generations. When Alexander set out to conquer the world, he constantly sent back unknown plants and biological specimens for Aristotle to study and catalogue.

Aristotle is the earliest natural historian whose work has survived in some detail. When he lived in the city of Mytilene on the island of Lesbos, Aristotle carried out extensive scientific research in zoology and marine biology. His work was summarized in the book known as *The History of Animals*, to which Aristotle added two short treatises, *On the Parts of Animals* and *On the Generation of Animals*. His detailed observations of a wide variety of organisms were without precedent, and some of the features of insects that he accurately reported were not again observed until the invention of the microscope in the 17th century. More than 500 animal species are described in detail in his treatises, and feature in his classification of animals into genus and species. Aristotle informs us of the anatomy, diet, habitat, modes of copulation and reproductive systems of mammals, reptiles, fish and insects. An example of his methods comes from *On the Generation of Animals* in which Aristotle describes breaking open fertilized chicken eggs at intervals to observe when visible organs were

generated. Aristotle gave accurate descriptions of the four-chambered fore-stomachs of ruminants, and of the ovoviviparous embryological development of the hound shark (where embryos develop inside eggs which are retained in the female's body until they are ready to hatch).

He made detailed observations of electric fish, catfish, angler-fish, octopus, the paper nautilus and cuttlefish. He described the use of the *hectocotylus*, an arm present on most cephalopods (octopus, cuttlefish, squid, nautilus etc.). The arm stores spermatophores and is modified to effect the fertilization of a female's eggs. This was widely disbelieved until its rediscovery in the 19th century. He distinguished between aquatic mammals and fish, and knew that sharks and rays were part of the group he called Selachē, selachians being the name now given to cartilaginous fish. There are some elements of superstition in his writings, but his research was conducted in a genuinely scientific spirit, and he always confessed ignorance when evidence was insufficient. Aristotle insisted that one must trust observation whenever there is a conflict between theory and observation; theories are to be trusted only if their results conform to observed phenomena.



Aristotle's classification of living things contains elements which still held sway in the 19th century. What the modern zoologist would call vertebrates and invertebrates, Aristotle called '*animals with blood*' and '*animals without blood*'. Animals with blood were divided into live-bearing (humans and mammals), and egg-bearing (birds and fish). Invertebrates were insects and crustacea. The latter he divided into non-shelled

(*cephalopods*), shelled and molluscs (*testacea*). Aristotle's *The History of Animals* classified organisms in relation to a hierarchical *scala naturae* (ladder of life), placing them according to complexity of structure and function so that higher organisms showed greater vitality and ability to move. Aristotle also wrote of the empirical scientific method, which became the classical model of scientific inquiry.

What is amazing is that all of the above is not Aristotle's only major contributions to thought. His intellectual range covering not just zoology, embryology, biology and botany, but chemistry, physics, history, ethics, rhetoric, metaphysics, logic, poetics, philosophy, political theory and psychology. Aristotle was the founder of formal logic, and his system was for centuries regarded as the essence of the discipline. He is best remembered as a philosopher. His writings about ethics and political theory, as well as in metaphysics and the philosophy of science, continue to be studied. He was the author of a philosophical and scientific system that became the framework and vehicle for both Christian scholasticism and medieval Islamic philosophy, and Aristotelian concepts remained embedded in Western thinking.

ORDER IN GOVERNMENT

NOT CONTENT with applying order to nature and thought processes, Aristotle created a system whereby governments could be ordered. The classification system distinguished between monarchies, oligarchies, tyrannies, democracies and republics and is still in use today.

BOTANY, PYROELECTRICITY AND SEX IN PLANT REPRODUCTION

—— *c*.320 BCE ——

THEOPHRASTUS (ORIGINALLY TYRTAMOS) OF ERESOS *c*.372–287 BCE, LESBOS, GREECE

A native of Eresos on the island of Lesbos, Theophrastus was a pupil of Plato and Aristotle, and with Aristotle founded the *Peripatetic school* of philosophy in Athens. Anti-Macedonian resentment flared in Athens and Aristotle was forced to flee, so Theophrastus became his chosen successor

at the Lyceum school in 322. Here he wrote a series of books on botany, including *The Natural History of Plants* and *On the Reasons for Vegetable Growth*. These survived as the most important contribution of antiquity to botany for 1500 years, and many of Theophrastus's scientific terms remain in use in modern times, such as *anthos* for flower, *carpos* for fruit and *pericarpion* for the tissue of the wall of a fruit. Rather than focus on formal causes, as Aristotle did, Theophrastus suggested a mechanistic scheme, drawing analogies between natural and artificial processes, and relying on Aristotle's concept of the 'efficient cause'.

Theophrastus also described the pollination of date palms and recognized the role of sex in the reproduction of some higher plants, though this knowledge was lost until Nehemiah Grew (1682) and Rudolf Jakob Camerarius (1694) rediscovered it. His works include elements of ecology, anatomy, pathology, morphology, seed germination, propagation, grafting, cultivation and medicine. He classified plants into trees (wooden plants), shrubs, under-shrubs, herbaceous perennial plants, vegetables, cereals and herbs. He noted that some flowers bear petals whereas others do not, and observed the different relative positions of the petals and ovary. In his work on propagation and germination, Theophrastus described the various ways in which specific plants and trees can grow – from seeds, from roots, from pieces torn off, from a branch or twig or from a small piece of stripped wood. Some of his taxonomic groupings of around 500 plants still survive, and his garden at the Lyceum is possibly the first botanic garden in history.

Aristotle bequeathed his library and manuscripts of his own writings to Theophrastus, and he took on Aristotle's mantle, in parts reshaping, commenting on and developing Aristotelian philosophy in an original way. His thinking leads to empiricism by means of observation, collection and classification. Theophrastus is said to have had 2000 disciples, and was esteemed by the kings Philippus, Cassander and Ptolemy. He was tried for impiety, but acquitted by the Athenian jury.

On Stones (314 BCE) is the earliest known work on minerals, their properties and applications. The first reference to the *pyroelectric effect* is made by Theophrastus, who noted that the mineral tourmaline becomes electrically charged when heated. Thus Theophrastus had described the first known mechano-chemical reaction. For two millennia afterwards, the peculiar properties of tourmaline were treated more as matters of mythology than scientific enquiry. However, in the 18th century pyroelectric studies made a major contribution to the development of our understanding of electrostatics. In the following century, research on pyroelectricity added to our knowledge of mineralogy, thermodynamics and crystal physics. Pyroelectricity gave birth to piezoelectricity in 1880 and to ferroelectricity in 1920. The field of pyroelectricity flourished in the 20th century with many applications, particularly in infrared detection and thermal imaging. Pyroelectric sensors have been carried on many space missions and have contributed significantly to our astronomical knowledge. Theophrastus also gave us the first description of any process for obtaining a pure metal from a compound. Unlike Aristotle, Theophrastus believed that the animals are capable of reasoning. He thought that as animals are superior to plants in this respect, it was not ethical to eat meat and for this reason he was a vegetarian. Theophrastus has been called 'the father of botany and ecology'. His spirit of enquiry is summed up in one of his aphorisms, quoted in Diogenes Laërtius, *Lives and Opinions of Eminent Philosophers c*.330 CE: '*Time is the most valuable thing one can spend.*'

DEVELOPMENT OF HUMAN RIGHTS AND DEVELOPMENT OF SCIENTIFIC METHOD

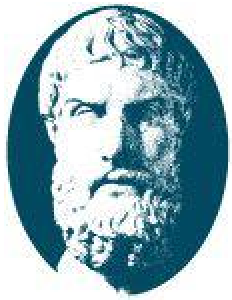
—— *c*.305 BCE ——

EPICURUS OF SAMOS 341–271/270 BCE, SAMOS, GREECE

A key figure in the development of science and of the scientific method, Epicurus developed materialistic metaphysics, empiricist epistemology and hedonistic ethics. He founded a philosophical school at Samos, before moving to Athens around 306 BCE. Epicurus taught that the basic constituents of the world are atoms, flying through empty space, and he tried to explain all natural phenomena in atomic terms. His rational materialism grew into a general attack on superstition and divine intervention: '*Is God willing to prevent evil, but not able? Then he is impotent. Is he able, but not willing? Then he is malevolent. Is he both able and willing? Whence then is evil?*' For Epicurus, the purpose of philosophy was to attain inner peace through the pursuit of the happy, tranquil life. He taught that pleasure and pain are the measures of what is good and evil, and that death is the end of the body and the soul and should therefore not be feared. The gods do not reward or punish humans, the universe is infinite and eternal, and events in the world are ultimately based on the motions and interactions of atoms moving in empty space. His theory differs from the atomism of Democritus because Epicurus believed that atoms do not always follow straight lines, and their direction of motion may occasionally exhibit a 'swerve'. This allowed him to avoid the concept of determinism and to affirm free will. Modern quantum physics also postulates a non-deterministic random motion of fundamental particles. Many of Epicurus's ideas about nature and physics presaged important scientific concepts of our time. He is a key figure in the development of the scientific method as he insisted that nothing should be believed, except that which had been tested through direct observation and logical deduction.

Epicurus's statement of the *Ethic of Reciprocity* (the 'Golden Rule') as the foundation of ethics is the earliest such formulation in Greece. It essentially states that you should treat others as you would like others to treat you. Equally, you should not treat others in ways that you would not like. This is probably the purest basis for the modern concept of human rights, in which each individual has a right to fair treatment, and a reciprocal responsibility to ensure justice for others. Elements of Epicurean philosophy have resurfaced in various diverse thinkers and movements throughout Western intellectual history, such as John Locke's assertion that people had a right to '*life, liberty and property*'. Epicurus's teachings influenced the leaders of the French and American revolutions, and Thomas Jefferson considered himself an Epicurean.

FOUR ELEMENTS



As across the globe we witness the exponential rise of multimillionaires and billionaires and their many excesses, all recorded faithfully by celebrity magazines, some of us find greater wisdom in Epicurus's writings: '*Luxurious food and drinks in no way protect you from harm. Wealth beyond what is natural is no more use than an overflowing container. Real value is not generated by theatres, and baths, perfumes or ointments, but by philosophy.*' In the second century ce, the Epicurean Greek Diogenes of Oenoanda carved around 25,000 words of Epicurus's teachings into a wall in Lycia (southwest Turkey). About a third has been recovered, of which this is a fragment.

FOUNDATION OF MATHEMATICS

—— *c*.300 BCE ——

EUCLID OF ALEXANDRIA *c*.330–*c*.260 BCE, EGYPT

For over 2000 years, all mathematical thought and expression flowed from the teachings of the Greek known as 'the father of geometry'. However, all we really know of Euclid is that he taught mathematics at the Great Library of Alexandria during the reign of Ptolemy I. Euclid's *Stoicheia* ('Elements') is the most enduring mathematical work of all time, drawing on the works of Thales, Pythagoras, Plato, Aristotle, Menaechmus, Eudoxus and others. Euclid had probably studied under students of Plato at Plato's Academy in Athens before he went to Alexandria, then the largest city in the world, and the centre of both the papyrus industry and the book trade. The 'Elements' has been the most widely used textbook of all time,

and even influenced Einstein to study mathematics. Since it was first printed in 1492, over 1000 editions have been published.

The ‘Elements’ is divided into 13 books which cover plane geometry, arithmetic and number theory, irrational numbers, and solid geometry. Euclid organized the known geometrical ideas, starting with simple definitions or axioms, formed statements called theorems, and set forth methods for logical proofs. Euclid believed that we cannot be sure of any axioms without proof, so he devised logical steps to prove them. He began with accepted mathematical truths, axioms and postulates, and demonstrated logically 467 propositions in plane and solid geometry. He used two main styles of presentation: synthesis (in which one progresses in a series of logical steps from the known to the unknown) and analysis (in which one posits the unknown and works towards it from the known, again via logical steps). Both methods were based on proved axioms, from which mathematical propositions, or theorems, were deduced. Euclid also wrote upon music, data, optics, ratios, astronomy and fallacies, but much of his writing has been lost. It was only in the 19th century that it was discovered that Euclid’s axioms were not absolute truths, paving the way for the development of a new kind of geometry which became the basis for the fields of quantum mechanics and relativity.

IMPORTANCE OF THE *ELEMENTS*

IN THE *Encyclopaedia Britannica*, the Dutch mathematician B.L. van der Waerden assessed the importance of the ‘Elements’ as follows: ‘*Almost from the time of its writing and lasting almost to the present, the* Elements

has exerted a continuous and major influence on human affairs. It was the primary source of geometric reasoning, theorems, and methods at least until the advent of non-Euclidean geometry in the 19th century. It is sometimes said that, next to the Bible, the Elements *may be the most translated, published, and studied of all the books produced in the Western world.'*

CONCRETE AND CEMENT

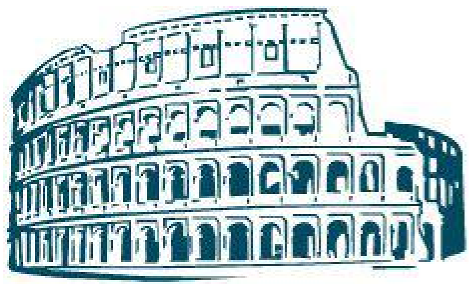
— *c.*300 BCE —

ROMAN ENGINEERS

Concrete is the most commonly used structural material in modern economies. In ancient times Assyrians and Babylonians used clay as the bonding substance or 'cement' in buildings, and the Egyptians used a lime and gypsum cement. However, the Romans from 300 BCE–476 CE pioneered the use of concrete across their empire. (Concrete is cement mixed with an aggregate such as small stones). Roman engineers used *pozzolana* cement (volcanic ash or powdered rock) from Pozzuoli, near Mt Vesuvius to build the Appian Way, Roman baths, the Coliseum and Pantheon, and also the Pont du Gard aqueduct in southern France. Limestone was common in many parts of their empire, so Romans also used lime mortar to manufacture a concrete, with aggregates of broken bricks and small stones (*caementa*). This cement mixture slowly dissolved in water, but it became almost as strong as modern concrete when mixed with pozzolana. Pliny reported a mortar mixture of one part lime to four parts sand, and Vitruvius reported a two parts pozzolana to one part lime mix. Animal fat, milk and blood were used as 'admixtures', added to cement to increase its bonding properties.

The Romans did not invent concrete, but a combination of pozzolanic concrete and outer surfaces of excellent stone, or good brick made of fired clay, allowed them to erect the massive structures which survive to this day. The mixture was placed in wooden frames and left to dry and bond with a facing of brick or stone, a little like the casting of statues in bronze or other metals. When completely dry, the wooden forms were removed, leaving behind solid concrete of great strength, although rough in appearance. This was often then covered with stucco or marble facing. Concrete walls were

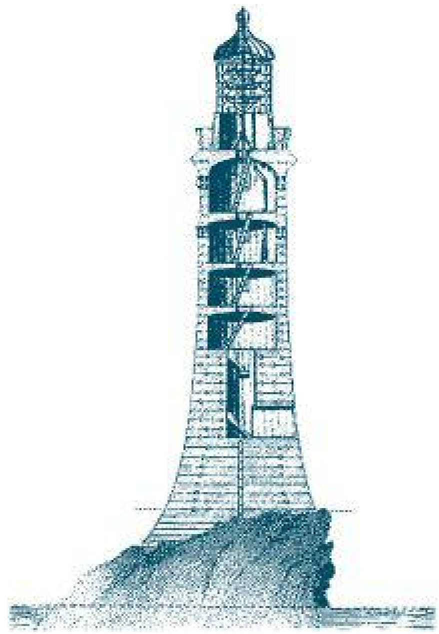
much less costly to construct than walls built of imported Greek marble, or even of local Italian tufa and travertine. It was also possible to fashion shapes out of concrete that cannot be achieved by masonry construction, especially the huge vaulted and domed ceilings (made without internal supports) that the Romans preferred over the post-and-lintel structures of the Greeks and Etruscans. Roman architecture thus became architecture of space rather than of sheer mass.



THE FIRST CIVIL ENGINEER AND THE CONCRETE LIGHTHOUSE

JOHN SMEATON (1724–92) designed windmills and water wheels, and also improved the efficiency of the steam engine by 50 per cent. He was involved in many significant works of engineering, including the construction of canals, bridges, mills and harbours. He was the first person to describe himself as a ‘Civil Engineer’ (i.e. non-military). He formed the Society of Civil Engineers in 1771. Until then most engineering works of any kind had been undertaken by the military. The president of the Royal Society recommended Smeaton for the work of reconstructing the lighthouse on the Eddystone Rocks near Plymouth. Huge waves and fires had destroyed previous lighthouses there. The shape of Smeaton’s lighthouse was inspired by that of an oak tree, tapering upwards from a wide base to give it greater stability. The base was constructed of blocks of granite, which were dovetailed into each other and the rock itself. He had carried out research into various materials which might be used for an effective mortar which could withstand the sea, developing a form of quick-drying concrete known as *hydraulic lime*. This is generally regarded as the first use of modern concrete in engineering. Smeaton also devised a crane which could lift the building materials up to the height of the developing lighthouse. In 1759 the Eddystone Lighthouse became operational, and survived until 1877, when cracks in the rock on which it was standing

began to threaten its stability. The lighthouse was dismantled and re-erected on Plymouth Hoe, where it still stands as a tourist attraction. The Eddystone lighthouse achieved fame worldwide, and became the standard design for lighthouses from then on. Smeaton did not patent any of his innovations, believing that the good of society came before personal financial reward.



After the fall of the Roman empire, the techniques and quality of cementing materials deteriorated. The practice of heating lime and volcanic rock was lost, but was reintroduced in the 1300s. The first real breakthrough came in 1756, when John Smeaton made the first modern concrete (hydraulic cement) by adding pebbles as a coarse aggregate, and mixing powered brick into the cement. In 1824, Joseph Aspdin (1778–1855) invented ‘Portland Cement’, a derivative of which is the dominant cement now used in concrete production. He created the first true artificial cement since Romans times by heating ground limestone and clay together and then pulverizing the mixture. The firing process changed the chemical properties of the materials, and Aspdin created stronger cement than by using plain crushed limestone. Aspdin called the product Portland cement because set mortar made from it resembled the best Portland stone, the most prestigious building stone in use in England at the time. Impervious to water, it actually becomes stronger if submerged after it has set. Samples of

concrete taken 30 years after a concrete boat sank during the First World War showed that the concrete had doubled its compressive strength.

Reinforced concrete (ferroconcrete) was invented in 1849 by Joseph Monier (1823–1906), who received a patent in 1867. He was a Parisian gardener who made garden pots and tubs of concrete reinforced with an iron mesh. Monier also promoted reinforced concrete for use in railway ties, pipes, floors, arches and bridges. Reinforced concrete is today the most commonly used structural material. Combining the compressive strength of concrete and the tensile strength of steel, reinforced concrete can be poured into forms and given any shape suitable to the channelling of loads. It can be sculpted to the wishes of the architect rather than assembled in prefabricated shapes. La Corbière Lighthouse in Jersey was Britain's first reinforced concrete lighthouse. It was completed in 1874 for £8000, including the causeway and lighthouse keepers' cottages. The other major part of concrete besides the cement is the aggregate. Aggregates include sand, crushed stone, gravel, slag, ashes, burned shale and burned clay. Fine aggregate (fine refers to the size of aggregate) is used in making concrete slabs and smooth surfaces. Coarse aggregate is used for massive structures or sections of cement. The strength of concrete depends on the ratio of water to cement, and of cement to sand and stone. Finer and harder aggregates (sand and stone) make stronger concrete; the greater the amount of water the weaker the concrete.

HELIOCENTRISM

—— *c*.260 BCE ——

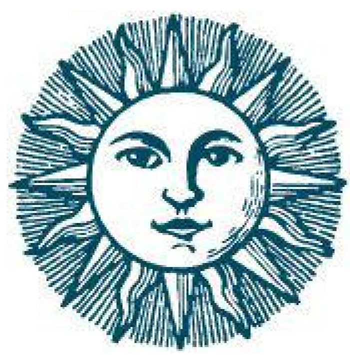
ARISTARCHOS OF SAMOS 310–*c*.230 BCE, GREECE

Aristarchos was the first man in Western civilization to deduce that the Earth moved around the Sun. He first managed to estimate the distances to the Sun and the Moon and their relative sizes. Aristarchos concluded that the Sun was much bigger than the Moon, and about 300 times bigger than Earth, and he reasoned that the Earth must therefore revolve around the Sun. This was the *heliocentric theory*. He also placed the planets in their correct order, orbiting around the Sun. Archimedes's view was that Aristarchos conflicted with the common teaching of the astronomers, and he quoted Aristarchos only to dismiss the theory disapprovingly. The

geocentric (Earth-centred) theories of Aristotle and Ptolemy held sway for over 1800 years until the work of Copernicus began to be accepted. Until Seleucus of Chaldea, about 150 years later, no astronomer in the West accepted the doctrine of the Sun-centred planets.

ARCHIMEDES'S DISAPPROVAL

ARISTARCHUS'S BOOK on the planetary system with the Sun in the centre has not survived, and we know of it only through references to its content, chiefly made by Archimedes. Archimedes wrote in *The Sand Reckoner*: '*You* [King Gelon of Syracuse] *are aware the "universe" is the name given by most astronomers to the sphere the centre of which is the centre of the Earth, while its radius is equal to the straight line between the centre of the Sun and the centre of the Earth. This is the common account as you have heard from astronomers. But Aristarchus has brought out a book consisting of certain hypotheses, wherein it appears, as a consequence of the assumptions made, that the universe is many times greater than the "universe" just mentioned. His hypotheses are that the fixed stars and the Sun remain unmoved, that the Earth revolves about the Sun on the circumference of a circle, the Sun lying in the middle of the Floor* [orbit], *and that the sphere of the fixed stars, situated about the same centre as the Sun, is so great that the circle in which he supposes the Earth to revolve bears such a proportion to the distance of the fixed stars as the centre of the sphere bears to its surface.*'



Because of his measurements, Aristarchos believed the stars to be very far away. This explained to him why there was no observable *parallax* (movement of the stars relative to each other as the Earth moves around the

Sun). However, we can now observe stellar parallax using telescopes. Thus to Aristarchos the stars were ‘fixed’ in the heavens. He therefore believed that the Sun was a fixed star, the closest one to the Earth. He claimed that at half-moon, the angle between Sun and Moon was 87°, the limits of human eyesight not enabling him to get a true value of close to 89° 50'. Aristarchos pointed out that the Moon and Sun have nearly equal apparent angular sizes, so their diameters must be in proportion to their distances from Earth. His geometry was correct, but the incorrect angle led him to conclude that the Sun was 18–20 times further away than the Moon, instead of around 400 times. (This false solar parallax of around 3° was used by astronomers up to 1600 and the invention of proper telescopes).

COMPOUND PULLEY

— *c*.250 BCE —

ARCHIMEDES OF SYRACUSE *c*.287–212 BCE, GREECE

Compound pulleys, such as block and tackles, enabled new building and navigational techniques, and are just one of many inventions attributed to Archimedes. This greatest scientist and engineer of antiquity was born in Syracuse, then an independent Greek state. His contributions to geometry revolutionized the subject, his methods anticipating integral calculus 2000 years before the work of Newton and Leibniz. Archimedes is now recognized as one of the three greatest mathematicians of all time, alongside Newton and Gauss. He was also a practical inventor, who developed a wide variety of machines. He was an expert in hydrostatics and mechanics, and is also regarded as ‘the father of mathematical physics’. Many of his writings survive. In mechanics he defined the principle of the lever, saying: ‘*Give me a lever long enough and a fulcrum on which to place it, and I shall move the world*’.

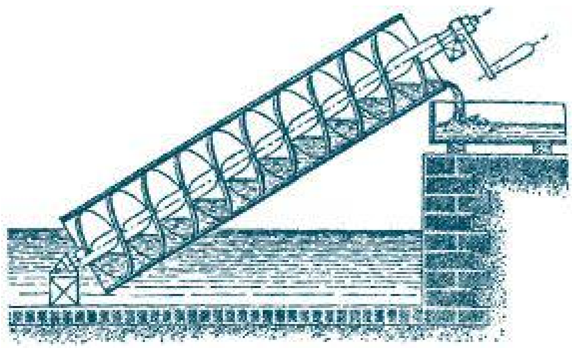
Plutarch reported that during the siege of Syracuse, Archimedes moved an entire Roman warship, laden with men, using compound pulleys with the *Archimedes Claw*. This invention of a ‘block and tackle’ has pulleys which are free to move and rotate while attached to a fixed block. By using a compound pulley, an operator can move a greater load with much less physical effort. A block and tackle can be used to lift heavy weights and to exert large forces in any direction. The system multiplies the strength and

pulling power of a winch, lowering the strain on the winch and the object being pulled. The weight reduction of a given load is increased by the number of pulleys used in a compound pulley system, so a system using four pulleys to lift a weight will feel as if the user is actually lifting one-fourth of the object's weight. Cranes use this principle, and the block and tackle system allowed heavy sails to be lifted far more easily by the crew of sailing ships, allowing for the building of much larger and better rigged vessels.

THE EUREKA! MOMENT

ARCHIMEDES WAS said to have shouted '*Eureka!*' ('I have found it!'), running naked from his bath, after he noticed that his body was displacing water. He realized that by measuring the displacement of water that an object produced, compared to its weight, he could measure its density. In *On Floating Bodies*, his fifth proposition (Archimedes's Principle) is that: '*Any solid lighter than a fluid will, if placed in the fluid, be so far immersed that the weight of the solid will be equal to the weight of the fluid displaced*'. This work laid down the essential principles of hydrostatics.

ARCHIMEDES SCREW



THE ARCHIMEDEAN water screw pump raises water from a lower to a higher level. Purportedly devised by Archimedes to expel bilge water from leaking ships, the screw that bears his name predates Archimedes by about 400 years. Archaeologists have established that earlier screws, which are capable of shifting water 'uphill', were used in the Hanging Gardens of Babylon in the seventh century BCE. So effective was the device, it is still used today in some sewage plants, in irrigation ditches, for draining marshy land and pumping out bilge water.

CALCULATION OF THE EARTH'S CIRCUMFERENCE

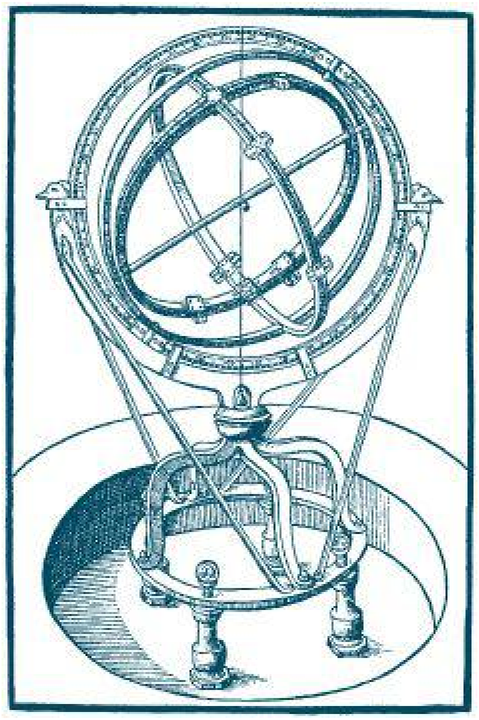
—— *c*.240 BCE ——

ERATOSTHENES OF CYRENE *c*.276–*c*.195 BCE, CYRENE (MODERN LIBYA)

Eratosthenes was the founder of geography and *prime number* research. Although most of Eratosthenes's writings are lost, many of his ideas are preserved through the works of commentators. This Greek athlete, poet, music theorist, mathematician and geographer is best remembered for the astonishing accuracy of his measurement of the Earth's circumference. As director of the great Library of Alexandria, he heard that there was a deep circular well at Aswan, Egypt. Once a year at noon on the summer solstice, it was entirely lit up by the sun. As Alexandria was almost due north of Aswan, he placed a vertical post and measured the angle of its shadow at that date and time. He assumed that the Earth was perfectly round and that the Sun's rays are essentially parallel. He knew from geometry that the size of the measured angle equalled the size at the angle of the Earth's centre between Alexandria and Aswan. Knowing also that the arc of an angle this size was 1/50 of a circle, he estimated that the distance between Alexandria

and Aswan was about 5000 stadia (500 miles/805 km), from the time it took him to reach there by camel. Eratosthenes then multiplied 5000 by 50 to determine the Earth’s circumference. His result, 250,000 stadia equals 25,000 miles (40,232 km), incredibly close to the 24,901 miles (40,075 km) we know today to be correct. Eratosthenes also determined the obliquity of the ecliptic (the Sun’s apparent path around the Earth), and measured the tilt of the Earth’s axis with great accuracy, ascribing it a value of 23° 51’ 15”. The Earth’s tilt causes the seasons, as he knew. Additionally he prepared a star map comprising 675 stars, suggested that a leap day should be added to every fourth year and accurately calculated the distance from the Earth to the Sun.

He was the first to use the word ‘geography’ (meaning ‘writing about the Earth’) and essentially founded the discipline of geography. He invented a system of latitude and longitude, introduced the climatic concepts of torrid, temperate and frigid zones and created a map of the world. Eratosthenes was also the founder of scientific chronology, recording the dates of major events from the conquest of Troy onwards in a book of history. Hipparchus credited Eratosthenes with the invention of the armillary sphere around 255 BCE, this being a spherical framework of rings representing celestial longitude and latitude and astronomically important features, such as the ecliptic.



TRIGONOMETRY, ASTROLABE AND THE PRECESSION OF THE EQUINOXES

—— *c*.150 BCE ——

HIPPARCHOS OF RHODES *c*.190–*c*.120 BCE, BITHYNIA (MODERN TURKEY)

Probably the greatest and most influential astronomer of antiquity, Hipparchos was born in Nicaea, Bithynia (now known as Iznik, Turkey). Nearly all of his writings have disappeared, but he was a Greek mathematician, astronomer and geographer. Hipparchos divided the circle into 360 degrees and created of one of the first trigonometric tables, leading to his being hailed as the inventor of trigonometry. Trigonometry is needed to solve measurement problems across all scientific fields. He solved several problems of spherical trigonometry, which advanced astronomy. As an astronomer, Hipparchos calculated the length of the year to within 6½ minutes and computed the distance to the Moon. Hipparchos's description of the slow motion of the points of solstice and equinox from east to west against the background of the fixed stars is perhaps his most famous achievement. He is therefore credited with the discovery of the *precession of the equinoxes*. He calculated for it a value of 46", which is close to our modern number of 50.26". Hipparchos devised an astronomical calendar,

and while his star catalogue does not survive today, it is believed that he included around 850 stars in it.

He also made a careful study of the motions of the Sun and Moon, making accurate models based upon observations and mathematical techniques, and could predict solar and lunar eclipses. For his observations, Hipparchos used an instrument described by Ptolemy as a dioptre, which may have been the first planispheric astrolabe. The device solved problems related to time and the position of the Sun and stars. By noting the position of the Sun, or of the brightest stars, a traveller could tell the time of day or night. Hipparchos researched a wide variety of astronomical questions, including the length of the year, the determination of lunar distance and the computation of lunar and solar eclipses. He developed theories for the Sun and Moon demonstrating, as Ptolemy explained, '*that they are represented by uniform circular motions*'. He thus seems to have been the first to propose a heliocentric solar system, but abandoned the work because his calculations showed that the orbits were not perfectly circular, as was believed to be mandatory by the scientists of his time. His model was followed for 2000 years until Copernicus demonstrated that the planets trace out elliptical orbits. Hipparchos used Chaldean astronomical material, both their methods as well as their observations. Ptolemy's later synthesis of astronomical knowledge was heavily dependent upon Hipparchos's discoveries.

TRIANGLES AND CHORDS

TRIGONOMETRY IS usually taught beginning with plane triangles, but its origins lie in the world of astronomy and spherical triangles. Before the 16th century, astronomy was based on the notion that the Earth stood at the centre of a series of nested spheres. To calculate the positions of stars or planets, one needed to use concepts to which we now refer as trigonometry. The earliest uses of trigonometric functions were related to the chords of a circle, and the recognition that the length of the chord subtended by a given angle x was (in modern terms) $2\sin(x/2)$. A chord is a line segment joining two points on any curve, and a straight chord passing through the centre of a circle is its diameter. Hipparchos produced the first known table of chords in 140 BCE, tabulating the value of the chord function for every 7.5 degrees. His work was further developed by Menelaus and Ptolemy of Alexandria

around 100 ce, who both relied on Babylonian observations and traditions. Ptolemy's table gave the value of chords for angles ranging from 0.5 degree to 180 degrees, in increments of half a degree.

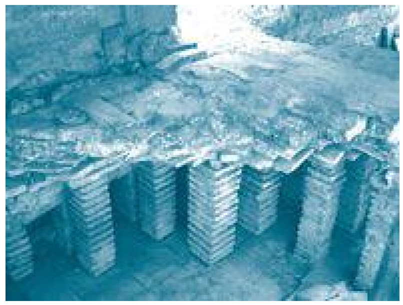
CENTRAL HEATING

—— *c.*25 BCE ——

SERGIUS ORATA FL. *c.*95 BCE, ROME

Without central heating, offices and factories would be restricted in size and height because of the problems of keeping them warm. It is difficult to envisage modern industry and commerce without this invention. In the Roman empire, central heating systems conducted air heated by furnaces through empty spaces under the floors and round pipes in the walls. The Roman systems were called *hypocausts*, a Greek word meaning 'fire beneath' or 'burning below'. The Roman writer and architect Vitruvius described the construction and operation of hypocausts around 25 BCE, attributing them to the merchant and hydraulic engineer Sergius Orata. Vitruvius added that fuel could be conserved by siting the mens' and womens' hot rooms for the public baths next to one another, adjacent to the tepidarium (cool room), to run the baths efficiently. Many remains of these hypocausts have survived in Roman architectural ruins in Europe, western Asia and northern Africa. Walking around these sites, one can see that the floor was raised above the ground by pillars, and spaces were left inside the walls. Thus hot air and smoke from the furnace would pass through these enclosed areas and out of flues in the roof, thereby heating but not polluting

the interior of the room. Ceramic box tiles were placed inside the walls, both to duct away the heated air and also to heat the walls. Rooms requiring the most heat were placed closest to the furnace, the heat of which could be increased by adding more wood to the fire. It was labour-intensive to run a hypocaust, as it required constant attention to tend the fire and was also expensive in fuel, so such a system was generally only found in villas or public baths.



However, it appears that a hypocaust lined with bitumen-coated bricks has been found at the great Indus valley site of Mohenjo-daro in Pakistan, which would predate the Roman invention by two millennia. Derivatives of the hypocaust were used in Castile and other former parts of the Roman empire, but when the Romans left Britain, central heating did not reappear there until around 1900. A similar system of central heating was used in Korea, known as a *gudeul* and later as an *ondol*. It is thought that the *ondol* system dates back to the Three Kingdoms era of 37 BCE–668 CE. Excess heat from stoves was used to warm homes. Smoke was drawn from a wood fire (typically used for cooking) to the underside of a thick masonry floor. However, the use of the *ondol* seems to be even earlier, with a Bronze Age *ondol* dating from 1000 BCE being found in North Korea. Franz San Galli (1824–1908), a Polish-born Russian businessman living in St Petersburg, invented the radiator between 1855 and 1857. This was a major step towards the modern central heating system we now use.

CHAPTER 3

CENTURIES OF INNOVATION

PAPER AND PAPERMAKING

— 105 CE —

T'SAI (CAI) LUN *c*.50–121 CE, CHINA

This was the greatest revolution in communications and literacy before the printing press. Around 6000 years ago the Sumerians wrote characters on clay blocks, but although this written communication was portable, it was not a practical medium because of its weight. Men experimented by writing on other surfaces, such as wood, stone, slate, ceramics, bark, metal, silk, tree leaves and bamboo. About 5000 years ago, Egyptians created 'sheets' of papyrus by harvesting, peeling and slicing reed into strips. The strips were then layered, pounded together and smoothed to make a flat, uniform sheet. Then parchment and vellum made from animal skins began to be used for writing. Paper (the name is derived from papyrus) was not actually invented until the second century BCE. Ancient paper fragments from the Xuanquanzhi ruins in China's Gansu province were made during the reign of Emperor Wu, who ruled between 140 and 86 BCE.

T'sai Lun served as a court eunuch from 75 CE, and was promoted under Emperor He of Han in 89 CE to take charge of manufacturing instruments and weapons. At this time, writings and inscriptions in China were generally made on tablets of bamboo, or on pieces of silk. However, silk was costly and bamboo heavy, so they were not convenient to use. Paper had existed in China for perhaps 200 years or so, but T'sai Lun was responsible for the first significant improvement in its quality, and for the

standardization of papermaking by adding essential new materials. In 105 CE T'sai Lun altered the composition for paper, using the bark of mulberry trees, bamboo fibres, remnants of hemp, rags of cloth, silk and fishing nets. Paper was made from felted sheets of these fibres suspended in water. The water was then drained, and the fibres allowed to dry into a thin matted sheet. He submitted this process to the emperor and received praise, but his exact formula has been lost.

Paper quickly became widely used as a writing medium in China. Papermaking has been hailed as '*one of the Four Great Inventions of Ancient China*', the others being the compass, gunpowder and printing. By the third century, the use of paper had enabled China to develop its civilization through the widespread dissemination of literature and literacy. By the seventh century, China's papermaking expertise had spread to Korea, Vietnam and Japan. In 751 some Chinese papermakers were captured by Arabs when a Tang army was defeated and so the knowledge of papermaking spread beyond the boundaries of China. The techniques of papermaking later passed from the Arabs to Europe in the 12th century. Paper replaced parchment and revolutionized communications across the world. Its use signalled the dawn of the *Scholastic Age* (*c*.1100–1150) across Europe and paper was fundamental to the success of Gutenberg press printing from 1439 onwards. George Bernard Shaw coined a memorable tribute to the importance of the medium when he wrote: '*Only on paper has humanity yet achieved glory, beauty, truth, knowledge, virtue, and abiding love.*'

WHEELBARROW

— *c*.231 CE —

ZHUGE LIANG 181–234 CE, CHINA

This simple 'second-class lever' made agriculture, mining and building construction much more efficient and economic. The wheelbarrow distributes the weight of its load between the wheel and the operator, enabling the convenient carriage of heavier and bulkier loads. A two-wheel type is more stable on level ground, while the almost universal one-wheel type has better manoeuvrability and allows greater control. Building inventories of 408–406 BCE at the Temple of Eleusis in Greece suggest the

presence of a one-wheeled load-bearing vehicle, but its use died out in Europe until around 1170–1250. There are many descriptions, murals and reliefs of Chinese wheelbarrows dating from the second century CE. Chen Shou (233–97 CE) compiled the *Records of the Three Kingdoms*, and credited the invention to the prime minister Zhuge Liang. He called his design the *Wooden Ox*, and it was used for transporting supplies in military campaigns. In 430 CE this design was described as consisting of a large single central wheel and axle, around which a wooden frame was constructed in representation of an ox. In the 11th century, Gao Cheng wrote that the small wheelbarrow then in use, with shafts pointing forwards so that it was pulled, was the descendant of Zhuge Liang's wooden ox. While the Chinese typically had the wheel in the centre of their barrows, European medieval barrows had their wheel at or near the front, and were pushed rather than pulled.

ACADEMICS AND WHEELBARROWS

'*They Tend to be suspicious, bristly, paranoid-type people with huge egos they push around like some elephantiasis victim with his distended testicles in a wheelbarrow terrified no doubt that some skulking ingrate of a clone student will sneak into his very brain and steal his genius work.*' William S. Burroughs, '*Immortality*' in *The Adding Machine: Collected Essays*, 1985

BREASTCOLLAR HARNESS

— *c.*450 CE —
China

This horse harness radically increased the efficiency of farming practices, allowing humans to cultivate and distribute a greater quantity and wider variety of crops. To plough a field before tractors, horses had to be harnessed to a plough. Harnessing made draft-animal agriculture possible. The wooden yoke had been developed first; it was attached around the neck of animals like oxen, allowing them to pull loads. However, yokes tended to choke horses, so different harnessing devices were developed. The *throat-girth harness* was developed in Chaldea in the third millennium BCE, and used successively in Sumer, Assyria, Egypt, Crete, Greece and Rome, but its attachment meant that the harder a horse pulled, the more strongly it choked off its own breathing. Because of these physical constraints, oxen were used in preference to horses for heavy work, as they do not have this problem due to anatomical differences, and could therefore be yoked to their loads. In Greece, harnesses were used to attach horses to chariots for use in warfare and for entertainment. The Chinese *breast-strap* or *breastcollar harness* was a major improvement on previous harnesses, which dated from the Warring States period of 481–221 BCE. The breastcollar harness, used widely across Europe by the ninth century, put pressure upon the sternum, where the line of traction is directly linked to the horse's skeletal system, allowing for almost full exertion of the horse for load carrying. However, it could only be used for lighter hauling, since it places the weight of the load on the sternum and the nearby windpipe. A major problem with a breastcollar harness was that the actual shafts of the cart, chariot or other vehicle are attached to a *surcingle* (wide leather strap) around the barrel of the horse. The breastplate primarily kept the surcingle from slipping back, and did not function as the primary pushing object. This results in the horse literally pulling the load, which is a less efficient use of the animal.

After the breastcollar harness, the next and final evolutionary stage was the collar harness. The *collar and hames* harness distributes the weight of the load onto the horse's shoulders, and thus avoids any restriction to the air supply. For heavy hauling, the harness must include the horse collar to allow the animal to use its full weight and strength, essentially allowing the horse to push forwards with its hindquarters into the collar. The horse could

now provide a work effort of 50 per cent more foot-pounds per second than the ox, as well as having generally greater endurance and ability to work more hours in a day. A single horse with a more efficient collar harness could draw a weight of about 1½ tons, and using horses and a slightly improved and heavier plough meant that peasant farmers could produce a surplus to trade in expanding markets. The 13th and 14th centuries also saw the widespread manufacturing of iron horseshoes, again increasing the efficiency of the horse. The replacement of oxen boosted the economy, reduced the incidence of subsistence farming and led to the rise of market-based towns and their associated commerce. The surplus in food allowed labour specialization and allowed the emergence of a merchant class within European society. The horse collar was a major factor in ending the feudal system and accelerated the transition from the Middle Ages.

PORCELAIN

—— *c*.650 CE ——

TAO-YUE *c*.608–676 CE, CHINA

The invention led to major trading across the Western and Eastern worlds. During the Eastern Han Dynasty period (196–220 CE), high firing glazed ceramic wares had developed into porcelain, but Tao-Yue is the legendary inventor of white porcelain during the Tang Dynasty of 618–906 CE. He used white clay (kaolin, now known as China clay), which he found along the Yangzte river where he was born. He added other types of clay and feldspathic rock to produce the first white porcelain, which he sold as *artificial jade* in the capital Chang-an. It was exported on a large scale to the Islamic world, where it was highly prized. By around 900, porcelain had been perfected, incorporating the translucent minerals quartz and feldspar. Porcelain was much finer than other clay ceramics, and so thin as to be translucent. Its white surface could be painted in many colours. Its toughness, strength and translucence arise from the formation of glass and the mineral millite when it is fired at temperatures between 2280 and 2640° F (1250 and 1450° C).

Porcelain was one of the most highly prized products that was exported from China, and it came to be generically called *china* in the English-speaking West. As trade with the Orient grew during the 1600s, porcelain became popular with the general public. The custom of drinking tea, coffee and chocolate became widespread and created a huge demand for porcelain cups and saucers. The secret of its manufacture was not discovered until the early 18th century in Europe, leading to the formation of the Meissen, Sèvres, Limoges, Chelsea, Derby, Worcester and Bow porcelain manufactories.

THE ORIGIN OF PORCELAIN

PORCELAIN derives its name from the Italian *porcellana* (cowrie shell) because of its resemblance to the translucent surface of the shell. The Cockney rhyming slang ‘my old China’, meaning ‘my old friend’, comes from ‘China plate’ which rhymes with ‘mate’.

GREEK FIRE

—— 672 CE ——

CALLINICUS (KALLINIKOS) OF HELIOPOLIS FL.672 CE, SYRIA

Greek fire kept the Eastern Holy Roman Empire secure from Islamic domination for 900 years. It was a highly combustible liquid that was projected from ‘siphons’ onto enemy ships or troops and was almost impossible to extinguish. Callinicus is credited with its invention. Born in Syria, Callinicus was a Jewish refugee who was forced to flee the Saracen (Arab) expansion, and he travelled to Constantinople. Seeing his homeland overcome, Callinicus determined not to let the same fate befall his new home. He experimented and discovered a specific combination of materials that was so insidious and effective that it helped to change the course of

history. He delivered the formula of his *marine fire* to the Byzantine emperor. The ingredients of what came to be called Greek fire were kept a state secret, known only to the Byzantine emperor and Callinicus's family, who manufactured it. The precise composition is still unknown, but it is generally accepted that it was a mixture of naphtha, pitch, sulphur, possibly saltpetre and other unknown ingredients. When exposed to air, the mixture spontaneously burst into fire and could not be extinguished with water. In fact, it would burn even when submerged in water. Comparable to modern napalm, there were few known substances that could extinguish it, with sand and urine being the two most commonly employed.

Its invention came at a critical moment in the history of the Eastern Holy Roman Empire. It had been seriously weakened by its long wars with Sassanid Persia, and the Byzantines had been unable to effectively resist the Muslim advance. Within a generation, Syria, Palestine and Egypt had fallen to the Arabs, who in 672 set out to conquer the empire's capital of Constantinople. Emperor Constantine IV Pogonatus (reign 668–85) was only 18 when he took the imperial throne at Constantinople. For some time Muawiyah, caliph of the Saracens, met with success against him. By 673 Muawiyah was in possession of the Asiatic shore of the Sea of Marmora and laid siege to Constantinople itself. Then the tide turned. The Byzantine fleet was armed with Callinicus's new weapon which was blown at opponents with bellows, a little like a flame-thrower. The Greek fire was used to great effect against the Muslim fleets, helping to repel them during the first and second sieges.

In order to use Greek fire effectively, the Byzantines had developed a large siphon that served as a propellant. It was mounted on the hull of the ship and operated in similar fashion to a syringe. Another great advantage was that it rarely backfired on its user. Historical sources derived from Roman, Greek, and Arab writers agree that it surpassed all other incendiary

weapons of the day in both its physical and psychological effect. The Arabs for instance employed a variety of incendiary substances similar to the Byzantine weapon, but they were never able to copy the Byzantine method of deployment by siphon, and used catapults and grenades instead. The Roman emperor recovered the mastery of the sea and drove off the Saracens. In 678 Muawiyah had to sue for peace, and hostilities were suspended for several years. Use of Greek fire was prominent in the Byzantine civil wars of 727 and 821–3 with the rebel fleets being defeated by the Imperial Fleet. The Byzantines also successfully used the weapon against the various Rus' and Bulgar attacks between the ninth and the 11th centuries.

THE FALL OF CONSTANTINOPLE

CONSTANTINOPLE WAS medieval Europe's largest and wealthiest city, withstanding attacks from the east and north for almost a millennium. 'The new Rome' dominated lands across Asia Minor, as well as modern Greece, Albania and Bulgaria. The forces of Islam could not break its power, but the doge of Venice, Philip of Swabia and Boniface of Montferrat plotted and diverted the 1203 Fourth Crusade, to attack the Christian capital of the Eastern Holy Roman Empire. Its emperor, Alexius III had made no preparations against this surprise attack by his fellow-Christians, who broke the chain protecting the Golden Horn and entered the harbour, where they breached the sea walls. In 1204 Constantinople was taken. Sir Steven Runciman wrote that the sack of Constantinople is '*unparalleled in history*': '*For nine centuries, the great city had been the capital of Christian civilization. It was filled with works of art that had survived from ancient Greece and with the masterpieces of its own exquisite craftsmen.*' The Venetians stole the four great bronze horses for St Mark's Basilica from the Hippodrome, and thousands of other treasures. For three days the French, Flemings and Venetians raped and pillaged in their bloodthirsty destruction of the Christian capital. '*In St Sophia itself, drunken soldiers could be seen tearing down the silken hangings and pulling the silver iconostasis to pieces, while sacred books and icons were trampled under foot. While they drank from the altar-vessels, a prostitute sang a ribald French song on the Patriarch's throne.*' (*A History of the Crusades*, 1951–4). Even nuns were raped in their convents. When order was eventually

restored among the sated Crusaders, citizens were tortured to find if there were any hidden treasures remaining. Within months Pope Innocent III, who had first called for the Crusade, bitterly lamented the spilling of '*blood on Christian swords that should have been used on pagans*' calling it '*an example of affliction and the works of Hell*'. As a result of this unprovoked attack upon the greatest city in Christendom, Constantinople lost power conclusively. In 1453, after being severely weakened by the Black Death, Constantinople was taken by the Ottoman Turks and the city has remained under Islamic rule ever since.

MECHANICAL CLOCK

—— 725 (*or* 723) CE ——
YI XING 683–727 CE, CHINA

Yi Xing (born Zhang Sui) built upon the work of predecessors and was a vital link to the creation of a reliable mechanical clock. Our sexagesimal system of time measurement (based on the number 60) dates back to the Sumerians, around 4000 years ago, and the Egyptians developed the system by dividing the day into two 12-hour periods. They invented water-powered clocks. Yi Xing, a Buddhist monk, astronomer, mathematician and mechanical engineer, made the first model of a mechanical clock in 725 CE. In 721, Yi Xing had been made a royal court astronomer in the Tang dynasty. He engaged in astronomic observation and calendar reform. Since the astronomical instruments at the palace were too worn out to be of any use, Yi Xing decided to design new ones. He first designed a model of the armillary sphere (a spherical astrolabe, a model of celestial objects). Armillary spheres had been designed and progressively improved since the

first century BCE in China, and Yi Xing added a sighting tube, mounted on the ecliptic ring for the better observation of celestial latitudes. He asked the emperor to have it cast in iron and bronze. In 724, the armillary sphere was successfully made and used to recalibrate the locations of 150 stars. The next year Yi Xing proceeded to create the structure of an elaborate water-powered armillary sphere, which reflected the regular motion of the Sun, the Moon and five major planets. He combined Zhang Heng's water powered celestial globe with a clockwork escapement mechanism. Additionally, it was an automatic hour-counter and a striking clock. The clock would hit a drum and strike every half-hour. His invention was recognized as the first astronomical clock in China. The clock operated by dripping water, which powered a wheel which made one full revolution in 24 hours. An iron and bronze system of wheels and gears made the clock turn. The Greek Philo of Byzantium described a water escapement mechanism for clocks in the third century, but Yi Xing's work was the basis of the first reliable mechanical clock in 1092, that of Su Song.

THE FIRST CLOCK

YI XING was famed for his genius, and a contemporary text describes his clock as follows: '[It] *was made in the image of the round heavens and on it were shown the lunar mansions in their order, the equator and the degrees of the heavenly circumference. Water, flowing into scoops, turned a wheel automatically, rotating it one complete revolution in one day and night. Besides this, there were two rings fitted around the celestial sphere outside, having the sun and moon threaded on them, and these were made to move*

in circling orbit … And they made a wooden casing the surface of which represented the horizon, since the instrument was half sunk in it. It permitted the exact determinations of the time of dawns and dusks, full and new moons, tarrying and hurrying. Moreover, there were two wooden jacks standing on the horizon surface, having one a bell and the other a drum in front of it, the bell being struck automatically to indicate the hours, and the drum being beaten automatically to indicate the quarters. All these motions were brought about by machinery within the casing, each depending on wheels and shafts, hooks, pins and interlocking rods, stopping devices and locks checking mutually.'

GUNPOWDER (BLACK POWDER)

—— *c*.830 CE ——
TANG DYNASTY ALCHEMISTS, CHINA

Gunpowder was the most destructive force in warfare and mining until Nobel's invention of dynamite. Gunpowder can be made by just using saltpetre (potassium nitrate) and charcoal, but without the addition of sulphur, the explosive power is not as strong. Sulphur also makes the powder easier to ignite. Although it can be used for causing explosions, the principal use of gunpowder is as a propellant. Gunpowder is made from a fuel (charcoal or sugar can be used) and an oxidizer (saltpetre), with sulphur added to allow for a stable reaction. Carbon from the charcoal, plus oxygen, forms carbon dioxide and energy. The reaction would be slow, however, like a burning wood fire, were it not for the oxidizing agent of saltpetre. Carbon in a fire must draw oxygen from the air, and saltpetre provides the necessary extra oxygen. Potassium nitrate, sulphur and carbon react together to form nitrogen and carbon dioxide gases and potassium sulphide. The expanding gases of nitrogen and carbon dioxide provide the propelling action. Gunpowder was the first chemical explosive, and no substitutes were invented until the later 19th century. It was the first known substance that would burn when packed into a tube. It is considered to be one of the *Four Great Inventions* of ancient China, the others being the compass, papermaking and printing. Not until 1267 did Roger Bacon in Europe record the main elements of gunpowder, then known as *black powder*.

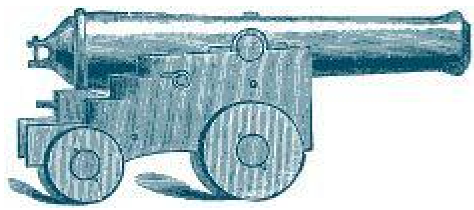
Emperor Wu Di (156–87 BCE) of the Han dynasty financed research by Taoist monks, to look into the secrets of eternal life. They experimented with sulphur and saltpetre, heating the substances in order to transform them. Ge Hong may have invented gunpowder in the third century. Later, in the Tang dynasty (618–907), sulphur and saltpetre were combined with charcoal (preferably from the willow tree) to create an explosive called *huǒ yào* ('fire medicine'), which we know as gunpowder. The ingredients were very carefully ground together because making gunpowder was highly dangerous. People would sometimes add water, wine or another liquid, since a single spark could result in a smoky fire. Once the powdered ingredients (known as *serpentine*) were mixed with a liquid, the mixture could be pushed through a screen to make small pellets, which were then allowed to dry. Gunpowder was first used to treat skin diseases and as an insect fumigant, before its advantage as a weapon was discovered. Experiments began with bamboo tubes filled with gunpowder.

THE FIRST REFERENCE

THE FIRST known reference of gunpowder is possibly this passage from a mid-ninth century Taoist text: '*Some have heated together sulphur, realgar* [arsenic sulphide] *and saltpetre with honey; smoke and flames result, so that their hands and faces have been burnt, and even the whole house where they were working burned down.*'

At some point, the Chinese attached arrows to these bamboo tubes, and fired them with bows to make fireworks. These developed into 'fire arrows' to scare enemies or set fire to their wooden forts. Soon it was discovered that 'gunpowder tubes' could launch themselves, just by the force produced by the escaping gas. Thus the rocket was born, now using metal tubes. The Chinese quickly developed gunpowder for warfare, producing a variety of weapons including flamethrowers, rockets, bombs and land mines. They then invented the cannon as a projectile weapon. From China knowledge was transmitted to the Arabs, and then to Europe. Al-Hassan claimed that the Mamelukes (warriors of the Turkish sultanate) used '*the first cannon in history*' against the Mongols in 1260 during the Battle of Ain Jalut in eastern Galilee. Explosive hand cannon were used by Mameluke Egyptians to frighten Mongol horsemen and cavalry, causing disorder in their ranks.

This was the decisive defeat in the great Mongol conquest, after which the Mongol threat subsided. Heavier and heavier cannon were invented, capable of projecting greater and heavier stone or metal balls. In the Welsh War of Independence (1400–15), the prince of Wales Owain Glyndŵr lost the great castles of Aberystwyth and Harlech after constant bombardment by the great cannon of the English army, marking the virtual obsolescence of castles in European warfare.



GUNPOWDER AND THE ELIXIR OF LIFE

GUNPOWDER WAS accidentally developed by monks and alchemists seeking the elixir of life. The following email was received by this author recently. It speaks for itself: '*A tough old cowboy from eastern Oregon counselled his grandson that if he wanted to live a long life, the secret was to sprinkle a pinch of gunpowder on his oatmeal every morning. The grandson did this religiously and lived in the best of health, to the age of 103. When he died, he left behind 14 children, 30 grandchildren, 45 great-grandchildren, 25 great-great-grandchildren and a 15-foot hole where the crematorium used to be.*'

DISTINCTION BETWEEN SMALLPOX AND MEASLES

—— *c*.900 CE ——

RHAZES *c*.865–*c*.925 CE, PERSIA (IRAN)

The recorded works of Rhazes (Abu Bakr Muhammad ibn Zakariyā Rāzī) remained the main sources of therapeutic medical knowledge until after the Renaissance. This Persian physician, alchemist, chemist, philosopher and scholar is recognized as a polymath, and biographies describe him as '*perhaps the greatest clinician of all times*'. Rhazes' most celebrated work is a 25-volume Graeco-Arabic compendium of medical and

surgical knowledge entitled *The Comprehensive Book on Medicine (Kitab al-Hawi fi al-tibb)*, generally known as *Al-Hawi*. The oldest copy dates from 1094 and is incomplete. Translated into Latin in 1279, it was the largest and heaviest of all books published before 1501. This massive book was directed at the general public, dedicated to the poor, the traveller, and the ordinary citizen who could consult it for treatment when a doctor was not available. The work contained information on many diseases, listing medical theories for each disease from Greek, Syrian, Indian, Persian and Arabic medicinal works. Following the tradition of Hippocrates, Rhazes supplied case histories, along with pragmatic suggestions for treatment. Rhazes advocated simple remedies, including dietary supplements, and warned against the dangers of complex preparations. The ninth book of *Al-Hawi* remained the main source of therapeutic knowledge until long after the Renaissance. Rhazes is considered the 'father of paediatrics', for writing *The Diseases of Children*, the first book to deal with child illnesses as an independent field of medicine, and he developed several chemical instruments that remain in use to this day.

Rhazes was the first physician to make an accurate distinction between smallpox and measles, accurately describing the symptoms of both. He told people to keep away from smallpox sufferers to avoid an epidemic. His descriptions avoided dogma, and relied upon clinical observation over a series of many cases. Rhazes is also known for having discovered 'allergic asthma' when describing rhinitis caused by smelling roses in spring, and was the first physician ever to write articles on allergy and immunology. Rhazes was the first to write that fever was a defence mechanism, the body's way of fighting disease. He criticized Galen's theory which declared that the body possessed four distinct *humours* which needed to be balanced, and Aristotle's theory of the *Four Elements*, causing other physicians to speak out against Rhazes. His *Book of the Secrets* contains practical advice on chemical manipulations. He believed in the transmutation of metals, and thought that metals were derived primarily from two elements, sulphur and mercury. He attempted to classify all known substances, dividing them basically into animal, mineral or vegetable categories. Rhazes is credited with discovering several compounds, including kerosene after distilling petroleum.

RHAZES AGAINST FANATICISM

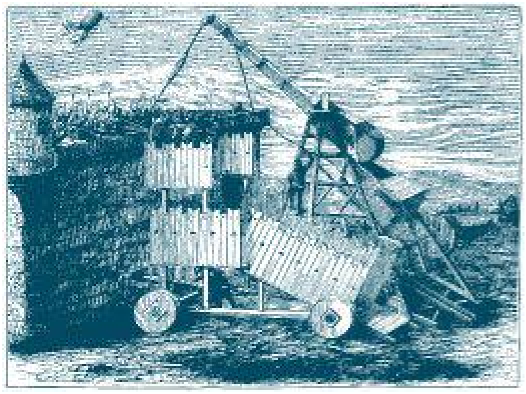
APART FROM his criticism of Galen's theory that the body possessed four *humours*, Rhazes was frequently in trouble for rejecting religious, as well as medical, dogma as fanaticism. He argued that religious fanaticism breeds hatred and wars. He wrote: '… *On what ground do you deem it necessary that God should single out certain individuals* [by giving them prophecy], *that he should set them up above other people, that he should appoint them to be the people's guides, and make people dependent upon them? … If the people of this religion are asked about the proof for the soundness of their religion, they flare up, get angry and spill the blood of whoever confronts them with this question. They forbid rational speculation, and strive to kill their adversaries. This is why truth became thoroughly silenced and concealed.*'

CONTINUOUS FLAMETHROWER AND BOMBS

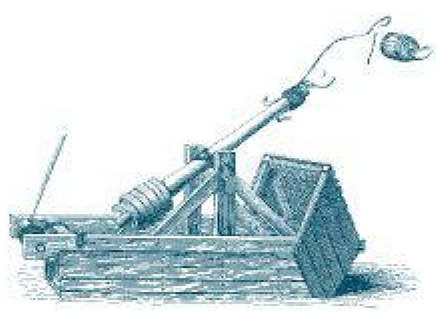
—— *c*.919 CE ——

ZENG GONGLIANG 998–1078 CE (HIS CHINESE CO-EDITORS FIRST DESCRIBED THESE IN 1044), CHINA

With the help of Yang Weide and Ding Du, Zeng Gongliang compiled the *Wujing Zongyao* ('The Collection of Most Important Military Techniques') from 1040 to 1044, describing subjects as diverse as catapults, compasses and warships. By the early tenth century, we see a gunpowder-impregnated fuse being used to light a Chinese two-piston flamethrower. This double-acting pump threw out a continuous stream of the Chinese version of 'Greek Fire' (an incendiary based upon petroleum), and was used in a battle in 932 CE. Earlier flamethrowers were not continuous. Flamethrowers have been used throughout history, including in the two world wars. In the Second World War Germany used flamethrowers to put down the Warsaw Ghetto uprising of 1943 and the Warsaw uprising of 1944. US Marines used flamethrowers to clear Japanese trench and bunker complexes. Where the Japanese were hidden deep in caves, the flames often consumed the available oxygen, thereby suffocating the occupants. The Marines still used their infantry-portable systems despite the arrival of adapted Sherman 'flame tanks'. The flamethrower is still probably the most terrifying military weapon encountered by infantry.



The *Wujing Zongyao* was the first book to record formulae for making gunpowder. One formulation is used for an explosive bomb launched by a trebuchet catapult, and another for a bomb with hooks so that it could attach itself to a wooden fort and set it on fire. Another was for a ‘poison-smoke’ bomb used in chemical warfare. The *Wujing Zongyao* stated that simple incendiary weapons were launched from catapults, thrown down from city walls at besiegers, or let down by iron chains from the top of the wall. There was also description of the *igniter ball* used in warfare and to find firing range: ‘*The igniter ball is made of paper round like a ball, inside which is put between three and five pounds of powdered bricks. Melt yellow wax and let it stand until clear, then add powdered charcoal and make it into a paste permeating the ball; bind it up with hempen string. When you want to find the range of anything, shoot off this fire-ball first, then other incendiary balls can follow.*’



THE CONTINUOUS FLAMETHROWER

THE *Pen Huo Qi* (‘fire oil throwing machine’) was an early Chinese piston flamethrower that used a substance similar to naphtha or petrol: ‘*On the right is the fierce fire oil-shooter. The tank is made of brass, and*

supported on four legs … Inside the cylinder there is a piston-rod packed with silk floss, the head of which is wound round with hemp waste about ½ inches thick … Before use the tank is filled with oil with a spoon through a filter; at the same time gunpowder is placed in the ignition chamber at the head. When the fire is to be started one applies a heated branding iron to the ignition chamber, and the piston-rod is forced fully into the cylinder. Then the man at the back is ordered to draw the piston rod fully backwards and work it back and forth as vigorously as possible. Whereupon the oil comes out through the ignition chamber and is shot forth as blazing flame … If the enemy comes to attack a city, these weapons are placed on the great ramparts, or else in outworks, so that large numbers of assailants cannot get through.'

CANAL POUND (CHAMBER) LOCK

—— 984 CE ——

QIAO WEIYO FL.984 CE, CHINA

China's construction of waterways to connect different parts of its vast territory produced some of the greatest early hydraulic engineering projects. One of the most impressive was the building of the Grand Canal, which connects Beijing to Hangzhou further south over a distance of 1103 miles (1775 km). Construction of the first Grand Canal began in the early 600s to connect the Yellow River (Hwang He) in the north with the Yangtze River (Chiang Jiang) in the south. The project lasted for many centuries, as it was constantly being enlarged and repaired. People could now send messages long distances and ships could carry rice back and forth. Moving boats up and down a steeply graded river or canal is a difficult task. In China, single sluice gates had been used to control canal *flash locks* since the first century BCE. The flash lock was a dam with a sluice gate that allowed the passage of boats. The sluice gate was opened temporarily, allowing boats to be carried downstream on a surge of water, while boats were hauled upstream using huge amounts of labour. A dyke-building project in 587 along the Yellow River established canal lock gates to regulate water levels for the canal. Double slipways were also installed over which boats were hauled when the difference in water levels was too great for the flash lock to operate. By 735, 165,000 tons (167,650 tonnes) of grain were being shipped every year

along the canal, and at its height there were 360,000 tons (365,800 tonnes) being annually moved by 8000 boats.

The Assistant Commissioner of Transport for Huainan, the engineer Qiao Weiyo had a recurring problem with barge traffic control on a section of the Grand Canal. Barges were often wrecked while passing the double slipways, and robbed of the tax they carried to pay to the canal authorities. He realized that by building two locks, one after the other, a pound of still water could be created between the lock gates. Then water from the higher side can be directed into the pound or chamber, raising the water level, and the boat with it. This system is still in use all around the world. Canal locks made carriage of goods far cheaper, transforming industry and allowing ships to make far shorter voyages by using great canals like those at Suez and Panama rather than having to circumnavigate land masses. The Chinese 'chamber lock' has been the basis of simpler canal transport, which continues to the modern day.

SONG SHI

THE 1345 *Song Shi* (one of the 'Twenty-Four Histories') stated that in 984: '*Their cargoes of imperial tax-grain were heavy, and as they were passing over they often came to grief and were damaged or wrecked, with loss of the grain and embezzlement by a cabal of the workers in league with local bandits hidden nearby. Qiao Weiyo therefore first ordered the construction of two gates at the third dam along the West River. The distance between the two gates was rather more than 50 paces* [250 feet, 76 m] *and the whole space was covered over with a great roof like a shed. The gates were "hanging gates"* [when they were closed]; *the water accumulated like a tide until the required level was reached, and then when*

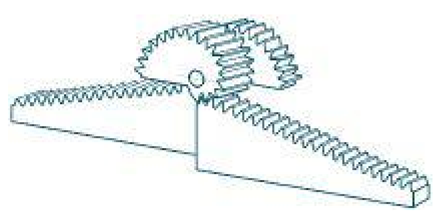
the time came it was allowed to flow out. He also built a horizontal bridge to protect their foundations. After this was done the previous corruption was completely eliminated, and the passage of the boats went on without the slightest impediment.'

SEGMENTAL AND EPICYCLIC GEARS

— *c*.1000 —

IBN KHALAF AL-MURADI FL.1000, ANDALUSIA, ISLAMIC SPAIN

This complex gearing allowed major advances in technology. Al-Muradi was an engineer and scientist who wrote *The Book of Secrets about the Result of Thought*, describing and drawing 31 machines and devices, including war machines, automatic calendars, the earliest Arabic description of water clocks and complex mechanical figures called automata. His rugged clocks were driven by fast-moving water and involved elaborate gear systems, sometimes lubricated by mercury – a feature not seen in Europe until the 13th century. All of his 31 models are run by water wheels, which regulate the intensity of fast-flowing water. Nineteen of the devices are water clocks. These measured time by marking the regulated flow of water through a small opening, and human or animal figurines (automata) marked or struck the hours. Other components used in his water clocks were siphons, float valve devices (similar to the valve in household toilets) and sump pumps that turn the device off or on according to the water level. Al-Muradi also described the use of an elevator-like lifting device in order to raise a large battering ram to destroy a fortress.



His text is the first to mention both segmental and epicyclical gears. A segmental gear is a piece for receiving or communicating reciprocating motion to or from a cogwheel. It consists of a sector of a circular gear, or ring, having cogs on the periphery, or face. In segmental gears one of a pair of meshing gear-wheels has teeth on only part of its perimeter, and the

mechanism permits intermittent transmission of power. Some machines included epicyclic gearing, in which small wheels are carried around on larger wheels. This is the earliest known description of such complex gearing apart from that of the Antikythera mechanism (an ancient Greek mechanical computer designed to calculate astronomical positions). It is thought that Leonardo da Vinci studied the book, which is held in the Biblioteca Medicea Laurenziana in Florence. Simple gears had been used in mills and water-raising machines, but this is the first known case of complex gears used to transmit high torque.

In Europe such gears were first seen in Giovanni de Dondi's 1365 astronomical clock, but these essential gearing mechanisms were rarely used until the early 16th century.

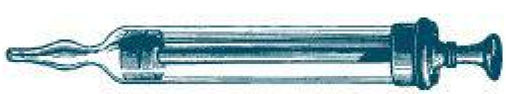
RECONSTRUCTING THE SECRETS

THE EMIR of Qatar recently funded a research team to transcribe the manuscript of *The Book of Secrets* and to translate it into Italian, English and French, and there will be a permanent exhibition relating to it at the Museum of Islamic Art in Doha. Two machines of *The Book of Secrets* were physically reconstructed: 'The Fortress Demolisher' and the 'Clock with three characters'.

MEDICAL SYRINGE

—— *c*.1000 ——

AMMAR IBN ALI AL-MAWSILI FL.1000, IRAQ AND EGYPT



A founder of ophthalmology, al-Mawsili invented the forerunner of the hypodermic needle. The first piston syringes had been used in Roman times, and were mentioned in *De Medicina* by the Roman doctor Aulus Cornelius Celsus (*c*.25 BCE–*c*.50 CE) for treating medical complications. The book was not printed until 1478, and it subsequently became important as a standard textbook. In the ninth century the physician-translator Hunayn ibn Ishaq wrote monographs on ophthalmology, including *Ten Treatises on*

the Eye that showed considerable advancement in knowledge over the Graeco-Roman works that we know today. Another ophthalmological manual covering 130 eye ailments was written by Ali ibn Isa al-Kahhal (d.1010) who practised in Baghdad. His contemporary was Ammar ibn Ali al-Mawsili, who was originally from Iraq but moved to Egypt. Here he dedicated his treatise on eye diseases to the Fatimid ruler al-Hakim, who ruled from 966 to 1020. Al-Mawsili discusses 48 diseases, some clinical cases and adaptations of surgical instruments, including a hollow cataract needle which he asserted could be used to remove a soft cataract from the eye by suction. This hollow glass tube is mentioned by later ophthalmologists, and the removal of a cataract by suction using a hollow needle was said to have been observed by the oculist Ibn Abi Usaybiàh around 1230.

LIGATURES, SURGICAL CATGUT AND ADHESIVE PLASTER

— *c*.1000 —

ABULCASIS 936–1013, ANDALUSIA, ISLAMIC SPAIN

Abulcasis (Abū al-Qāsim Khalaf ibn al-Abbas Al-Zahrawi) introduced over 200 surgical instruments. He described how to ligature blood vessels, and his use of catgut for stitching is still used in modern surgery. He was court physician to the caliph of Andalusia, and his 30-volume encyclopaedia of medical practice (*Kitab al-Tasrif*) was studied by Islamic and European surgeons for over five centuries. It summarized what he had learned over a period of 50 years. His specialization was curing illness by cauterization, burning damaged tissue to seal amputations, prevent blood loss and halt infections such as septicaemia complications. Before the advent of antibiotics there was no real alternative to dealing with many illnesses or wounds. Ambroise Paré (1510–90) is credited with having introduced the ligature of arteries instead of cauterization during amputation, but Abulcasis was the first to describe the procedure of tying blood vessels. He introduced catgut for internal stitching, as it will dissolve in the body without any adverse consequences.

The so-called *Walcher postion* in obstetrics and *Kocher's method* for treating a dislocated shoulder were also first described by Abulcasis, centuries earlier than their usual attribution. Abulcasis was the first to

describe the then fatal condition of ectopic pregnancy, and he made a device to save the patient. He invented many surgical instruments for removing foreign bodies or inspecting parts of the body. Abulcasis discovered that haemophilia was hereditary, and even performed migraine surgery. He pioneered the preparation of medicines by sublimation and distillation, and provided recipes for drugs. Just some of the innovations listed in his works are the adhesive plaster, curette, several new types of scalpel, retractor, surgical hook, surgical rod, surgical spoon, oral anaesthesia, inhalation anaesthesia, anaesthetic sponge, cotton dressings and surgical catgut.

ADHESIVE PLASTER

IN 1830, Samuel D. Gross reported his use of medicated adhesive plasters to treat body fractures in a Philadelphia medical journal. In 1845, Dr Horace H. Day and Dr William H. Shecut of New Jersey patented an adhesive plaster painted with rubber dissolved in a solvent, which was marketed by Dr Thomas Allcock as *Allcock's Porous Plaster*. In 1848, Dr John Parker Maynard of Massachusetts announced a plaster consisting of a fluid derived from gun cotton dissolved in sulphuric ether. It was brushed on the skin and covered with cotton strips. In 1874, Robert W. Johnson and George J. Seabury, working in New Jersey, developed a medicated adhesive plaster with a rubber base. In 1886, Johnson left Seabury to set up his own business, Johnson & Johnson, and almost 900 years after Abulcasis' invention his plasters called *Band-Aids* with their rubber base became commercially viable.

CONTAGIOUS DISEASES

—— 1025 ——

AVICENNA *c*.980–1037, PERSIA (IRAN)

Avicenna (Abū `Alī al-husayn ibn Abd Allāh ibn Sīnā) was a Persian chemist, theologian, mathematician, philosopher, poet, geologist and astronomer, the most famous polymath of the Islamic Golden Age, whose medical treatises were consulted across the known world. Of his 450 treatises, 40 are concerned with medicine. His 14-volume, million-word *Canon of Medicine* followed the principles of Galen and Hippocrates. It

includes five books. The first book discusses physiology and the second examines pathology and hygiene. The third and fourth books deal with the methods of treating diseases, and the fifth describes the composition and preparation of remedies. It was the standard medical text across Europe and the Islamic world until the 18th century. Avicenna is credited as being the first person to document correctly the anatomy of the human eye and to note that the heart contained a valve.

Avicenna seems to have been the first to write of contagious diseases and he recommended quarantine to limit their spread. Europeans contested his claims that tuberculosis was contagious, but he was found to be correct. Avicenna introduced experimental medicine and efficacy tests. His rules and principles for testing the effectiveness of new medications and drugs still form the basis of modern clinically controlled trials and clinical pharmacology. Sir William Osler called Avicenna the '*author of the most famous medical textbook ever written*', noting that the *Canon of Medicine* remained '*a medical bible for a longer time than any other work*'.

MODERN ALGEBRA

—— 1070 ——

OMAR KHAYYáM 1048–1122, PERSIA (IRAN)

The foundation of modern algebra led to major advances in astronomy and mathematics. The Persian known to us as the poet Omar Khayyám (Ghiyath al-Din Abu'l-Fath Umar ibn Ibrahim Al-Nishapuri al-Khayyami) was also a mathematician, astronomer and philosopher. As an astronomer, it appears that Khayyam proposed that the Earth was not the centre of the universe, centuries before Copernicus. He built an observatory, and led work on compiling astronomical tables. In 1079 Khayyám measured the length of the year as 365.24219858156 days, such a precise measurement that it only accumulates a one-hour error every 5500 years. In comparison, the standard Gregorian Calendar of 1582, which we use today, has a 24-hour error every 3330 years. His calendar was used until the 20th century and is the basis for the Iranian calendar still used in Afghanistan and Iran. It is based upon actual solar transit, and so is similar to Hindu calendars. The lengths of the months vary between 29 and 31 days, depending on when the Sun crosses into a new area of the zodiac. His famed star chart has been lost, but it appears that many of his ideas passed down to scholars over the generations.

AVICENNA AND THE SEA-COVERED EARTH

'*Mountains have been formed by one* [or other] *of the causes of the formation of stone, most probably from agglutinative clay which slowly dried and petrified during ages of which we have no record. It seems likely that this habitable world was in former days uninhabitable and, indeed, submerged beneath the ocean. Then, becoming exposed little by little, it petrified in the course of ages.*' Avicenna, *Congelatione et Conglutinatione Lapidium*, 1021–3 (trans. E.J. Hohnyard and D.C. Mandeville 1927)

THE QUATRAINS

The Rubáiyát [Quatrains] *of Omar Khayyám* is the title given by Edward Fitzgerald (1809–83) to his translation of a selection of hundreds of poems attributed to Omar Khayyám. The following verses are among the best-known: *A Book of Verses underneath the Bough, A Jug of Wine, a Loaf of Bread – and Thou Beside me singing in the Wilderness – Oh, Wilderness were Paradise enow! The Moving Finger writes: and, having writ, Moves on: nor all thy Piety nor Wit Shall lure it back to cancel half a Line, Nor all thy Tears wash out a Word of it.*

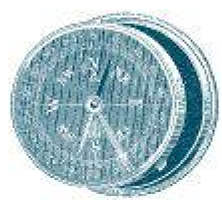
The third-century Diophantus of Alexandria is considered the 'father of algebra', but Khayyám certainly advanced the science considerably. His *Treatise on Demonstration of Problems of Algebra* (1070) made his name across the medieval world as a leading mathematician. The work laid out the principles of algebra, part of the body of Persian mathematics that was eventually transmitted to Europe. In particular, Khayyám derived general methods not only for solving cubic equations but also for some higher orders. He found a geometric solution to cubic equations, which could be used to derive a numerical answer by consulting trigonometrical tables. In this regard Khayyám's work can be considered the first systematic study, and it resulted in the first exact method of solving cubic equations. It contained a complete classification of cubic equations with geometric solutions found by means of intersecting conic sections. A major achievement in this text is Khayyám's discovery that a cubic equation can have more than one solution. Remarkably, he stated that the solution of cubic equations requires the use of conic sections and that they cannot be solved by the compass and straight edge method. A proof of this impossibility was demonstrated only 750 years after Khayyám died.

MAGNETIC COMPASS AND TRUE NORTH

—— 1088 ——

Shen Kuo (Shen Gua) 1031–1095, China

The polymath Shen Kuo was the first person to discover that the compass did not point to true north, but to the magnetic North Pole. This was the decisive breakthrough that made compasses more useful for navigation. Shen Kuo completed his scientific work *Meng Xi Bi Tan* (‘Dream Pool Essays’) after his retirement. To aid his work in astronomy, Shen Kuo had improved designs of the armillary sphere, gnomon (the indicator which casts a shadow on a sun dial), sighting tube, and invented a new type of inflow water clock. In the field of mathematics, he developed techniques that laid the foundations for ‘spherical trigonometry’ and high-order arithmetic progressions. The compass had been invented around 247 BCE in China, but this was a non-magnetic device known as ‘the South-pointing chariot’. Before the compass, position at sea was generally determined by the sighting of landmarks, supplemented by celestial bodies. The first compasses had allowed courses to be kept in overcast weather, and opened up the *Age of Discovery*.



In his *Dream Pool Essays*, Shen was the first man to describe the magnetic needle compass, which could be used for navigation across the world. It was Shen who discovered the concept of *true north*, in terms of magnetic declination towards the North Pole, with experimentation of suspended magnetic needles. He wrote that steel needles were magnetized once they were rubbed with lodestone, and that they could be suspended in floating position or in mountings. Because magnetic north and magnetic south vary from the geographical true north and south, navigators could adjust their courses based upon Shen’s finding of the magnetic declination. Magnetic declination varies widely, depending upon the further one is from the prime meridian of the Earth’s magnetic field. Today, the local declination is given on sea charts, to allow the map to be oriented with a compass parallel to true north. As well as giving mariners true reckonings at sea, Shen wrote that it was preferable to use the 24-point rose instead of the old eight cardinal compass points. This was shortly afterwards adopted for navigation and later expanded to 32 for even greater accuracy of heading.

Around 100 years later, Alexander Neckam recorded the first Western reference to the magnetic compass, in around 1180.

THE FIRST PALEOCLIMATOLOGIST?

SHEN FOUND fossilized seashells and pebbles like those often found on the seashore in mountain terrain, leading him to conclude that at some time in the far past, the mountain had been at sea level. In *Dream Pool Essays*, he devised a geological hypothesis for land formation (geomorphology), based upon findings of inland marine fossils, knowledge of soil erosion and silt deposition. He also proposed a hypothesis of gradual climate change. He had observed petrified bamboos that were preserved underground, in a dry northern habitat which could not support bamboo growth in his time. It is well beyond the scope of this book to record all the inventions, discoveries and achievements of this remarkable '*Chinese da Vinci*'.

TOWER CLOCK AND CHAIN DRIVE

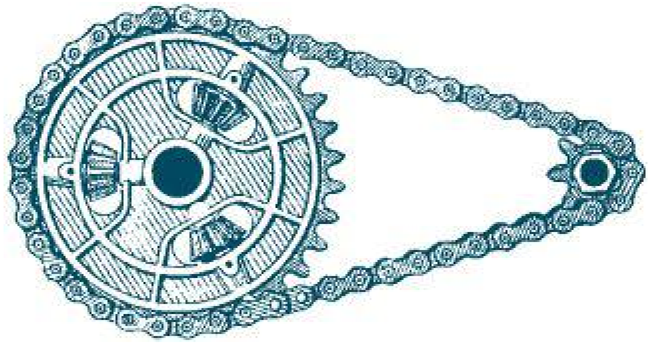
—— 1092 ——

SU SONG 1020–1101, CHINA

This first reliable mechanical clock had a power-transmitting drive which later found application during the Industrial Revolution. The Chinese Buddhist monk Su Song invented it to drive astronomical models used for astrological purposes (predicting the future for the emperor). Su Song's *Cosmic Engine* was 35–40 feet (10.6–12.2 m) high, and at its apex was a power-driven armillary sphere for observing the positions of the stars. Power was transmitted from water dripping from a waterwheel by Su Song's invention – the *chain drive*. A celestial bronze globe, on the middle level inside the tower, turned in synchronization with the armillary sphere above. There were 36 buckets attached to a central waterwheel, and each

would sequentially trip a lever and tilt forward to engage a system of gears and counterweights. An extremely efficient escapement mechanism converted this energy from a pendulum to the gears, a system unknown in Europe for another two centuries. Yi Xing (683–727 CE) had previously used this type of escapement, with waterwheel scoops filled by *clepsydra* drip. The clepsydra was a device for drawing liquids from vats too large to pour, which utilized the principle of air pressure to transport the liquid from one container to another. (The later development of manual escapements allowed clocks to become even more precise). On the lowest level of Su Song's three-level tower clock, mechanically-operated mannequins (automata) would exit mechanically opened doors at fixed times in the day, ringing bells and banging gongs and drums, before returning behind their doors once again.

The *celestial ladder* inside the tower is the oldest-known endless power-transmitting chain drive. This transmitted the power from the waterwheel to turn the armillary sphere and power the clock. Drive belts transmit mechanical power from one place to another, and they had been used for a thousand years in China, but they were generally prone to stretching and slippage. Su Song used a drive belt to transmit power from the water clock tank and waterwheel, but it had holes in the links of an endless chain, which pass over the teeth in a sprocket gear. Plans for the clock tower and illustrations of the chain drive can be seen in Su Song's treatise about the clock tower, *Xinyi Xiangfayao*, which was written in 1092 and officially printed in 1094. Su Song's inventive type of chain drive, operating along a system of fixed sprockets, can still be seen in today's bicycles and motorbikes, and has been an important technology since its Western employment, by Jacques de Vaucanson in 1770 for a silk reeling and throwing mill. J.F. Tretz first used the chain drive in a pedal-powered bicycle in 1869.



THREE-FIELD SYSTEM

— *c*.1100 —

EUROPE

This was the main method of farming in Europe from the Middle Ages until the 19th century. The pattern of agriculture represented a decisive advance in production techniques. In the previous *two-field system*, each season half the land was sown to crop and half left fallow (the soil being allowed to rest and recover). Crop rotation is necessary in order to avoid the build-up of crop-specific soil pests and diseases, and because different families of plant have varying nutritional requirements. In the *three-field system* only a third of the land was unused, lying fallow. In the autumn a third of available land was planted with wheat, barley or rye. In the spring another third of the land was planted with oats, barley and legumes to be harvested in late summer. The legumes (peas, lentils and beans) improved the soil by their nitrogen-fixing ability and at the same time provided food for human consumption. Spring planting required summer rains, so was most effective in northern Europe, providing two harvests a year and reducing the risk of crop failure and subsequent famine. The cultivation of a surplus of oats, obtained from the spring planting, also provided horse feed. This in turn made possible the agricultural use of the horse, instead of oxen, after the introduction of the padded horse collar.

In what became known as the *Green Revolution* of the 1940s–70s, the traditional practice of crop rotation was replaced in many parts of the world by the practice of supplementing the natural chemical inputs to the soil through top dressing with synthetic fertilizers, e.g. adding urea or ammonium nitrate and restoring soil pH with lime. Other initiatives also included the development of high-yielding varieties of cereal grains, expansion of irrigation infrastructure, modernization of management techniques, distribution of hybridized seeds and improved pesticides. From the 1960s agricultural production increased markedly. This is an important part of the constant search for increased yields throughout the world, preparing soil intensively for specialist crops, and reducing waste and inefficiency by simplifying planting and harvesting.

THREE BECOMES FOUR

A *FOUR-FIELD system* was popularized by the British agriculturist Charles 'Turnip' Townshend (1674–1738). This system (wheat, barley and a root crop such as turnips and clover) produced both a fodder crop and a grazing crop allowing livestock to be bred year-round. (In much of western Europe plentiful rain may not only allow cattle and sheep to feed on a field for much of the year, but also for up to three crops of grass to be cut and stored for winter feed). This increased productivity by eliminating the need to leave the soil uncultivated every third year. The new crop rotation was a key development in the British agricultural revolution.

MIND-BODY RELATIONSHIP IN MEDICINE

—— *c*.1180 ——

MAIMONIDES 1135–1204, CORDOBA, ISLAMIC SPAIN

This Spanish rabbi was a pre-eminent philosopher, and one of the greatest Torah scholars and physicians of the Middle Ages. He was appointed personal physician to the great Saracen leader Saladin, but declined the position of the physician to Richard the Lionheart. Maimonides (Moses ben-Maimon) knew that the Christian Third Crusade co-led by the vicious King Richard I was also a Crusade against the Jews in Israel. (Richard had already been responsible for the massacre of British Jews). Maimonides's three most significant works dealt with philosophy and Jewish commentary: *Commentary on the Mishneh*, *Mishneh Torah* and *The Guide to the Perplexed*. He also wrote ten known medical works that were translated from Arabic to Latin throughout the Middle Ages. Maimonides's compendia became organized guides to medicine for medieval physicians. They circulated through large European Renaissance cities such as Bologna, Venice and Lyon, and became a source of transmission of medical knowledge from one era to the next.

Maimonides described the symptoms, diagnosis, pathology and treatment of many diseases, including stroke, diabetes, liver inflammation, pneumonia and asthma. He believed in treating disease by removing the underlying cause. Maimonides advocated disease prevention through hygiene, fresh air, clean water, exercise and healthy diet. He wrote that a person's physical well-being depended on his or her mental health and vice versa. His descriptions of the mind-body relationship were original ideas, not made by his predecessors. The philosophy of a healthy mind in a healthy body was positively promoted by Maimonides. Writing in *The Lancet* in 2001 Sidney Bloch noted that: '*Psychosomatic medicine, especially as pioneered by psychoanalysts after World War II, owes a debt to Maimonides; indeed, he could well be crowned the original psychosomaticist.*' Unlike his contemporaries, he was not afraid to criticize the works of his predecessors, such as Galen and Hippocrates. His own findings were based on rigorous scientific experimentation, observation and interpretation.

ST FIACRE, THE PATRON SAINT OF SUFFERERS OF HAEMORRHOIDS

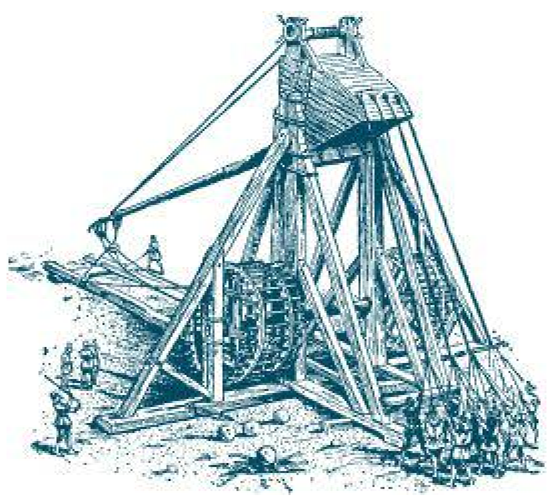
ST FIACRE (d.670) was an Irish monk who travelled to France and developed a monastic garden. He suffered from piles, but one day sat on a stone and was cured. Haemorrhoids were called *Saint Fiacre's illness* or *curse* in the Middle Ages, as was any fistula. St Fiacre's reputed aversion from women is believed to be the reason he is also known as the patron saint of venereal disease sufferers. Fiacre is thus officially the patron saint of sufferers of piles, fistulas and venereal diseases, but is mainly remembered as the patron saint of growing food and medicinal plants, and as the patron saint of gardeners. He is also the patron saint of taxi cab drivers, box makers, florists, hosiers, pewterers, tile makers, ploughboys and those suffering from barrenness – a mixed portfolio, all in all. Regarding piles, Maimonides disagreed with the standard practice of his day. Instead of the surgeon cutting haemorrhoids out, or burning them, Maimonides prescribed today's most common treatment of a sitz bath (sitting in a bath with water up to the hips).

COUNTERWEIGHT TREBUCHET

— 1187 —

MARDI BIN ALI AL-TARSUSI FL.1187, SYRIA

Amongst al-Tarsusi's writings was a military treatise for Saladin with the inspiring title of '*Information for the intelligent on how to escape injury in combat; and the unfurling of the banners of instruction on equipment and engines which assist in encounters with enemies.*' In it, he gives us the first record of the counterweight trebuchet, which transformed siege warfare. (A trebuchet is a type of catapult that works by using the energy of a raised counterweight to throw a projectile.) Al-Tarsusi claimed the trebuchet to have the same hurling power as a traction machine pulled by 50 men, owing to '*the constant force* [of gravity], *whereas men differ in their pulling force*'. His siege-engine is distinguished from the earlier traction trebuchet (invented around the fourth century BCE) which required a team of men pulling the missile, rather than using a counterweight. The first counterweight trebuchets could fling projectiles of up to 350 pounds (160 kg), at high speed, into enemy forts and defended cities.



Disease-infected corpses of humans and animals were also flung over walls to demoralize and potentially infect the defenders. A favourite ploy was hurling the heads of captured prisoners over the defences. It is believed that the first counterweight trebuchet may have been used in the First Crusade at the Siege of Nicaea in 1097 by Byzantines and crusaders. Nicaea was defended by 200 towers, and Raymond IV of Toulouse used a siege engine to damage the Tower of Gonatas. Saladin used 17 siege engines in his attempt to take the city of Tyre from the Crusaders in 1187–8. These

new gravity-powered machines were used in the Third Crusade by Richard I of England and Philip II of France in the Siege of Acre (1189–91). Huge rocks were aimed at the walls, eventually leading to the fall of the city. Al-Tarsusi gives us the first picture of a counterweight trebuchet, the use of which spread quickly across the Islamic and European worlds. However, he describes them as '*infidel machines*', inferring that the Crusaders had invented them first. Before the advent of cannon, trebuchets were the most important siege engine to take enemy cities, being developed to hurl stones over a ton in weight, or a variety of objects in one load. At the Siege of Lisbon in 1147, two machines fired missiles at a rate of one every 15 seconds, and the average range was over 1000 feet (305 m).

ZERO

—– 1202 (in *Liber Abaci*) —–

FIBONACCI (LEONARDO OF PISA) 1170–1250, ITALY

Without zero, modern physics and mathematics could not have progressed. However, there are two very different uses of zero. One use is as an *empty place* indicator in our place-value number system. Thus, in a number like 7035, the zero (0) is used so that the positions of the 7 and 3 are correct. We know that 735 means something quite different. In Kush in Mesopotamia, around 700 BCE, the symbol for zero was something like 3 hooks, reading . On Babylonian cuneiform tablets from around 400 BCE we see two wedge symbols indicating 7035, which would then read something like 7ΔΔ35. Thus our zero was used as some sort of punctuation mark in this context. In Babylon, 70350 would similarly be marked 7ΔΔ35ΔΔ, when an end place zero was needed. The Greeks began their work in mathematics around 400 BCE, around the time that zero as an *empty place indicator* was coming into use in Babylon. The Greeks however did not adopt the positional number system we know today. Early Greek mathematics was based on geometry, and mathematicians did not need to name their numerals since they worked with numbers as lengths of lines. Numbers which required to be named for records were used by merchants, not mathematicians, and hence no different notation was needed. However, some astronomers began to need a notation for zero to record data, and began to use the symbol O as an empty place indicator.

THE INDEPENDENT DISCOVERY OF ZERO

ANOTHER CIVILIZATION also developed a place-value number system with a zero, namely the Maya people who lived in Central America, occupying the area which today is southern Mexico, Guatemala and northern Belize. Their civilization flourished particularly between 250 and 900 ce. At least by 665, the Mayans used a place-value number system to base 20 with a symbol for zero. However their use of zero stretches back further than this and was in use before they introduced the place-valued number system. To some, this implies that South America may have been settled by Phoenicians or other early travellers.

However, the second use of zero is *as a number itself*, in the form we use it as 0, the whole number exactly between -1 and +1, a negative unit and a positive unit. Today's numerals and number system were born in India. Although we are unsure of its antiquity, we know that zero as a number between -1 and +1 was part of Indian mathematics by 650 CE. The Indians also used a place-value system, with zero being used to denote an empty place. Brahmagupta (598–670) attempted to give the rules for arithmetic involving zero and negative numbers in the seventh century. He explained that given a number, if you subtract it from itself you obtain zero. He gave the following rules for addition and subtraction which involve zero. The sum of zero and a negative number is negative, the sum of a positive number and zero is positive, and the sum of zero and zero is zero. A negative number subtracted from zero is positive, a positive number subtracted from zero is negative, zero subtracted from a negative number is negative, zero subtracted from a positive number is positive, zero subtracted from zero is zero. He also says that any number when multiplied by zero is zero. He is the first person that we know who tried to extend arithmetic to negative numbers and zero.

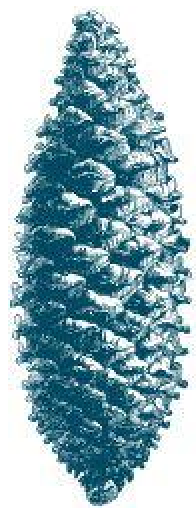
In due course the brilliant work of the Indian mathematicians was transmitted to Islamic and Arabic mathematicians to the west. In Iraq, al-Khwarizmi (*c*.790–850) wrote *On the Hindu Art of Reckoning*, describing the Indian place-value system of numerals based on 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0. Indian ideas spread east to China as well as west to the Islamic countries. The important link between the Hindu-Arabic number system and European mathematics is Italian mathematician Fibonacci's massive

volume *Liber Abaci*. Fibonacci described the Hindu-Arabic numerals and the place-valued decimal system for expressing numbers that we use today, and gave detailed instructions on how to compute with them (a process that became known as *algorism*, which subsequently led to the modern word algorithm). Fibonacci himself always referred to the numerals as 'Hindu', but later writers introduced the term 'Hindu-Arabic', and later 'Arabic'. His first chapter begins: '*These are the nine figures of the Indians: 9 8 7 6 5 4 3 2 1. With these nine figures, and with this sign 0 which in Arabic is called zephirum, any number can be written, as will be demonstrated.*' (Our name zero actually derives ultimately from the Arabic *sifr* which also gives us the word cipher.) However, the progress of the adoption of number systems and zero in Europe was extremely slow. Girolamo Cardano (1501–76) in his *Ars Magna* solved cubic and quartic equations without using zero, as zero was still not part of his mathematics. Only in the 1600s did zero begin to come into widespread use.

THE FIBONACCI SEQUENCE

THE FIBONACCI Sequence, or Fibonacci Numbers are obtained by adding two consecutive numbers from a sequence to get the next one following them, i.e. 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, 1597 … The sequence has amazing properties, and is found in nature underpinning the structure of vegetables, fruit, seed heads, pine cones, leaf arrangements and so on. For instance, flowers only have a Fibonacci number of petals. Tree branches rotate around the trunk in a pattern based on Fibonacci numbers. Also the ratios are important. If you divide a Fibonacci number by the previous number, the ratio is almost the same number, e.g. 34/21 = 1.619047619; 55/34 = 1.617647059; and 89/55 = 1.618181818. Like pi, the Fibonacci ratio, known as *phi*, is an irrational number. There can never be an exact result, but it is very nearly 1.61803398874989, mathematically expressed as $(\sqrt{5} + 1)/2$. Phi is also called the *Golden Section* (or *Golden Cut*) number, which is mentioned by Euclid who called it 'dividing the line in mean and extreme ratio'. If you divide the line so that the longer part is phi times (about 1.62) the shorter part, it is divided in the golden section (or golden cut). The *Golden Rectangle* is one where the length and the width of the rectangle are in the golden ratio, the length being approximately 1.62 times the width. The

golden rectangle and golden section are extremely important in art and architecture. The golden ratio is commonly used in everyday design, for example in the shapes of postcards, playing cards, posters, wide-screen televisions, photographs and light switch plates. With related numbers it is also used in financial trading markets, in trading algorithms, applications and strategies. Typical forms include *Fibonnaci retracement*, *Fibonnaci time extension*, the *Fibonnaci arc* and the *Fibonnaci fan*.



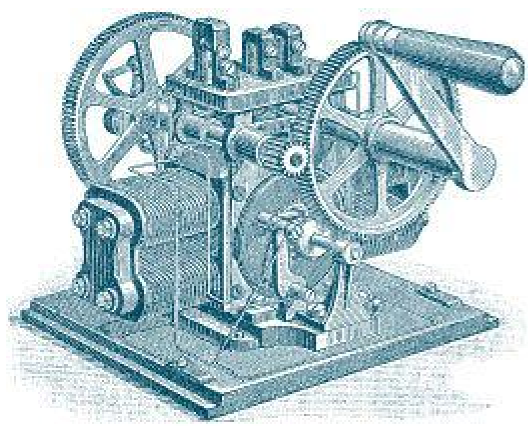
CRANKSHAFT, CAMSHAFT AND SUCTION PUMP

—— 1206 ——

AL-JAZARI 1136–1206, AL-JAZIRA, UPPER MESOPOTAMIA

The crankshaft converts rotary into linear reciprocating motion, and vice-versa, and is used in a huge number of machines such as steam and internal combustion engines. The Industrial Revolution could not have happened without crankshafts and camshafts. The Arabic polymath al-Jazari (Abū al-'Iz Ibn Ismā'īl ibn al-Razāz al-Jazarī) is renowned for writing the *Book of Knowledge of Ingenious Mechanical Devices*, in which he describes 50 such devices with instructions on how to construct them. He describes timber lamination, grinding of seats and plugs of valves, casting of metals in mould boxes, an escapement mechanism, water mills, combination locks etc. There are five machines for raising water, in which he incorporates his most important ideas and components. A crank – the eccentrically mounted handle of a rotary handmill – was first seen in Spain in the fifth century

BCE. We then see it with a connecting rod mechanism in a third century Roman sawmill. Al-Jazari invented an early crankshaft, incorporated with a crank-connecting rod (shaft) mechanism in his twin-cylinder piston suction water pump, and also his chain pump. Cattle provided the energy for the piston suction pump to bring water from wells for irrigation. This was the origin of the suction pump. His other invention, the chain pump was run by water power, and used in city water supply systems. Today's crankshaft is essentially the same as al-Jazari's design.



A *cam* is a rotating or sliding piece, in a mechanical linkage, that transforms rotary motion into linear motion or vice-versa. It is often a part of a rotating eccentric wheel or shaft with an irregular shape, which strikes a lever at one or more points on its circular path. A cam can be a simple tooth, for instance used to deliver pulses of power to a steam hammer, or an eccentric disc or other shape, which produces a smooth reciprocating motion in the *follower*. This follower is a lever which makes contact with the cam. The camshaft, the shaft (or cylinder) to which cams are attached, was used by al-Jazari in his automata, water clocks and water-raising machines. Among his automata was a waitress which served drinks, and a hand-washing automaton incorporating a flush mechanism as is now used in flush toilets. His cam and camshaft did not appear in European mechanisms until the 14th century. Camshafts are used in today's internal combustion engines in conjunction with a timing belt, allowing precise coordination of the intake of fuel and output of exhaust with the firing of the combustion chambers.

BUTTONHOLE

— *c*.1235 —

PROBABLY AN ARABIC INVENTION, FIRST DOCUMENTED IN GERMANY

Buttons have been present throughout much of human history, and they became the universal method of fastening clothes in the 19th and 20th centuries, but it took the invention of the buttonhole to popularize them. The earliest evidence comes from 13th-century German sculptures, which show tunics featuring six buttons running from neck to waist. Buttons come in two basic types. A *shank button* has a raised area on the back of the button which is used to sew on the button. The deeper the shank, the stronger the fastener can be. The later four-hole button does not offer the decorative possibilities of the shank button, because of the four sewing holes in its centre. Primitive man used thorn and sinew to hold clothing together, and bone stick pins were also used. With the introduction of metals came metal pins and tied loops. The button was originally used more as an ornament than as a fastening, the earliest known being around 5000 years old and made of a curved shell and found in the Indus Valley. Some buttons were carved into geometric shapes, with holes drilled in them, to be fastened to clothes with thread or sinew. On Chinese Bronze Age sites (*c*.2000–1500 BCE), buttons have been found which were used to decorate belts and other metal objects. The Egyptians used cloth ties, and brooches or buckles to hold their clothes together. The Greeks and Romans are thought to have worn buttons to actually fasten clothes, but using fabric loops.

THE BUTTON AND ZIP MONOPOLY

In 1980 three brothers in Qiaotou, China, started up a business by picking buttons off the street. Twenty-five years on, the town makes almost every zip and button we wear. Since 2006, 60 per cent of the world's buttons are made in Qiaotou, which churns out 15 billion buttons a year from 700 family-run factories. The town boasts that it has 1300 button shops selling 1400 varieties of buttons. It also makes 125,000 miles (200 million metres) of zippers a year. Buyers come from all over the world, attracted by prices of less than a penny a zip. The town ships more than two million zips a day, making it the biggest supplier in China's 80 per cent share of the international zip market. Nearby, the city of Hang Ji is the global centre for toothbrush manufacture, as is Sheng Zou for ties, Zhang Qi for cheap cigarette lighters and Wen Ling for shoes. All of these products are sold across the globe under well-known Western brand names. Also close is Yiwu which makes more socks than anywhere else on Earth. There, Lanswe, the biggest sock and stocking manufacturer in the world, spins out five million socks a day, mostly for export.

Around 1250 the provost of Paris established laws governing French craft guilds, including the Button-Maker's Guild. They were making buttons in the true modern sense, thanks to the invention of the buttonhole, probably introduced into Europe by Crusaders returning from the Middle East. This invention had a great impact on fashion, since fabrics could now be overlapped and buttoned. Buttons soon became widespread with the rise of form-fitting garments across Europe. However, buttons were still mainly used for decoration. Most clothing was still closed with lacing or hooks, and garments did not use buttons as methods of closing on a regular basis until the last half of the 16th century. Most of the buttons were small, but over the next century or so they became larger and very ornate, often using precious metals and jewels as symbols of rank and fortune. The French king Francis I (1494–1547) had 13,600 gold buttons on a single costume.

During the American War of Independence, the buttons attached to Washington's armies' uniforms were all imported from France. Because of the blockade of 1812, Aaron Benedict of Connecticut bought thousands of brass pots and pans to roll buttons in his own mill and begin button manufacturing in America. With mass production during the Industrial Revolution, buttons became popular for women's clothing, but many of their clothes were still fastened with lace and hooks. England became the

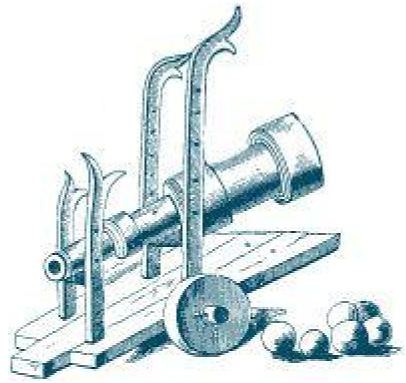
world's leading button-maker, with the men's four-hole button becoming the norm. After the First World War, the button became far more popular in the more 'man-tailored' fit of female clothing. With cheap costume jewellery, the desire for ornate shank buttons all but disappeared. Zips began to take over the function of buttons, e.g. for the fly on men's trousers and for blousons. Velcro is also a new substitute, used when age or illness makes fingers useless, or when ripping a garment off quickly without tearing it is desired.

EXPLOSIVE WEAPONS OF WAR

—— *c*.1370 ——

JIAO YU FL.1350 AND LIU JI 1311–1375, CHINA

Chinese military technology led the world from the 12th century onwards. Two military men, Jiao Yu and Liu Ji, aided the foundation of the Ming dynasty (1368–1644) by helping to overthrow the Mongol Yuan dynasty. They wrote a military treatise *Huolongjing* ('Fire Dragon Manual') that enlightens us about Chinese military technology of the mid-14th century. In the manual are included fire lances, grenades, land mines, naval mines, cannons, exploding cannonballs, rockets, poison flamethrowers, handguns, two-staged rockets and poison gas. Gunpowder-based 'fire' weapons had been used as early as the Song dynasty (960–1279). Fire lances and fire tubes, combinations of a firearm and flamethrower, were made in many different ways and illustrated in the *Huolongjing*, the earliest having been constructed using bamboo tubes in the tenth century. By the 12th century fire lances and fire tubes were made from metal. Some firearms sent a *lotus bunch* of arrows, and some low-nitrate gunpowder flamethrowers used poisonous mixtures, including arsenic trioxide. The oldest known bronze handgun has been dated to 1288, and handguns and bombards are known to have been used in battle in that year. Bombards are large, muzzle-loading cannon or mortars that are used for firing stone cannonballs.



The first cannon-barrel design known is shown in a stone sculpture dated to 1128, probably a bombard, and the oldest bronze cannon known dates to 1298. In 1341 Zhang Kian wrote that the cannonball could '*pierce the heart or belly when it strikes a man or horse, and can even transfix several persons at once.*' Jiao Yu called it a bronze '*eruptor*'. Some cannon held large rounds that produced a bursting charge upon impact, which he called the '*flying-cloud thunderclap eruptor*'. The Chinese had learned how to pack hollow cast-iron shells of cannonballs with gunpowder, to create an explosive effect upon contact with enemy targets, an invention not known in Europe until the 16th century. What the *Huolongjing* called the '*poison-fog magic smoke eruptor*' had blinding or poisonous gunpowder packed into hollow shells, which would burn and choke the enemy. By the 12th century, one gunpowder formula could send a *fire-stone* (cannon-ball) around 400 yards (365 m). Each cannon could have its own carriage so as to be rotated at will.

Land mines were used in 1277 during the Song dynasty to kill invading Mongols. They were made of cast iron, and their fuses were ignited when enemy movement disturbed a trigger mechanism. The pin release mechanism dropped weights to rotate a spinning steel wheel that worked as a flint to spark and light the underground fuses. Naval mines were constructed using slow-burning joss sticks that were disguised as driftwood etc., and timed to explode against enemy ships. Specific types of gunpowder had different uses, and exploding grenades could be thrown or catapulted. Some bombs and grenades were filled with hundreds of bits of porcelain and iron pellets, coated with faeces, urine, and extracts of poisonous plants, sal ammoniac etc., to poison any survivors of the blast.

Fire arrows had been used almost since the invention of gunpowder; they were gunpowder-impregnated and fired by a bow or ballista, However, by the time of the *Huolongjing*, they resembled rockets, an invention from the Southern Song dynasty of 1127–79: ‘*One uses a bamboo stick 4 feet 2 inches (127 cm) long, with an iron arrow-head 4.5 inches (11.5 cm) long … behind the feathering there is an iron weight 0.4 inch (1 cm) long. At the front end there is a carton tube bound on to the stick, where the rising gunpowder is lit. When you want to fire it off, you use a frame shaped like a dragon, or else conveniently a tube of wood or bamboo to contain it.*’ The *Huolongjing* tells us of the advance of combining a fire lance with the rocket launching tube, to make a hand-held rocket launcher.

PRINTING PRESS

—– *c*.1436–1440 —–

JOHANNES GUTENBERG 1398–1468, MAINZ, HOLY ROMAN EMPIRE (GERMANY)

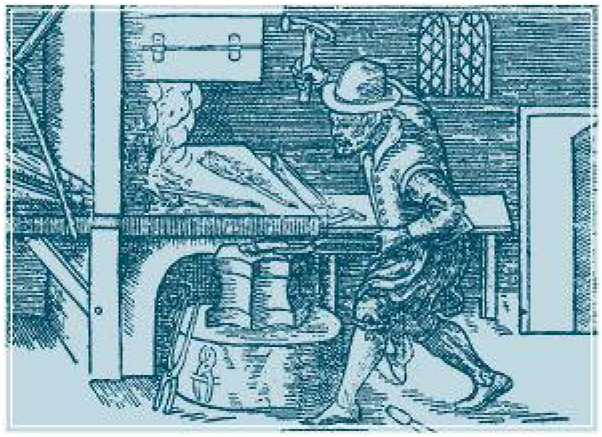
The printing press transformed communications and accelerated learning and development across Europe. Gutenberg was a blacksmith and goldsmith, and his invention is widely regarded as the single most important event of the second millennium. It is the defining moment of the Renaissance, what Eisenstein called the ‘*agent of change*’ in the transformation of medieval society, and sparked what is known as the ‘Printing Revolution’. Although movable type had been invented in China around 1040, Gutenberg was the first European to use movable type printing, and he invented the first printing press. His mechanical device consisted of a wooden agricultural screw press modified for printing, which could produce 3600 pages per day. It was a hand press, in which ink was rolled over the raised surfaces of movable hand-set block letters held within a wooden form, and the form was then pressed against a sheet of paper. He also invented a process for mass-producing movable type and developed an oil-based ink. This combination of press, new ink and movable type (originally wooden and later metal) was the first practical system which allowed the mass production of printed books that was economically viable

for printers and readers alike. Standardized movable type documents replaced handwritten manuscripts and woodblock printing, which were the existing methods of book production in Europe, and revolutionized European book-making.

By the start of the 16th century, printing presses were operating in over 200 cities in a dozen European countries, producing more than 20 million volumes. By 1600 their output had risen to an estimated 150 to 200 million copies, while Gutenberg book printing technology spread rapidly outside Europe. The relatively free flow of information transcended borders and induced a sharp rise in contemporary literacy, learning and education. It allowed the circulation of revolutionary ideas among the rising middle classes, and also among working peasants, threatening the traditional power monopoly of the ruling nobility. Typed pamphlets became a key factor in the rapid spread of the Protestant Reformation. Thus began the era of mass communication, instrumental in fostering the gradual democratization of knowledge and enabling the rise of the press. Pamphlets could now be distributed criticizing political and religious leaders. Printing played the major role in the development of the Scientific Revolution, laying the basis of the modern knowledge-based economy. Gutenberg's major publication was the 1455 *Gutenberg Bible* (the '42-line Bible'), acclaimed for its high technical quality. He was bankrupted after a dispute with a local moneylender who had given him credit and was exiled. Not until the last three years of his life were his achievements recognized.

THE GUTENBERG BIBLE

IN THE 1920s a New York book dealer bought a damaged Gutenberg Bible, dismantled the book and sold sections and individual leaves to book collectors and libraries. These leaves now sell for as much as $20,000–100,000 each depending upon the condition and the desirability of the page. Only 21 complete Gutenberg Bibles dating from 1455 are known to exist. One was sold in 1978 for $2.2 million, and the next and last sale was to Japan in 1987 for $5.4 million, a record at auction for a printed book. The price of a complete copy today is now estimated at $25–35 million or more. Gutenberg was not to realize that this Bible, which was created using new technology, would actually cause a great schism in Christianity: ‘*It is a press, certainly, but a press from which shall flow in inexhaustible streams … Through it, God will spread His Word. A spring of truth shall flow from it: like a new star it shall scatter the darkness of ignorance, and cause a light heretofore unknown to shine amongst men.*’ Johannes Gutenberg, quoted in W.J. Federer *America’s God and Country: Encyclopedia of Quotations*, 1994



CHAPTER 4

RENAISSANCE TECHNOLOGY AND THE SCIENTIFIC REVOLUTION

INFINITE UNIVERSE, ELLIPTICAL ORBITS, OTHER INHABITED WORLDS

—— 1440 ——

NICHOLAS OF CUSA 1401–1464, BERNKASTEL-KUES, HOLY ROMAN EMPIRE (MOSELLE VALLEY, GERMANY)

Nicholas of Cusa (Nikolaus von Kues, Nicolaus Cusanus) was the first man known to posit that the Earth and Sun were not the centre of any universe, and that planetary orbits were not perfectly circular. This German cardinal is considered one of the great geniuses and polymaths of his time, a statesman, theologian, philosopher, mathematician and astronomer. He played a notable part in the power struggle between the Vatican and the Holy Roman Empire. He was the first to use concave lenses to correct myopia, and made important contributions to the field of mathematics, developing the concepts of the infinitesimal and of relative motion. Nicholas's work was essential for Leibniz's discovery of calculus and for Georg Cantor's research into infinity. Kepler, Bruno, Copernicus and Galileo were all aware of his writings. Nicholas said that no perfect circle can exist in the universe. This opposed the Aristotelian model, and also Copernicus's later assumption of circular orbits. However, Nicholas influenced Kepler's model, which postulated elliptical orbits of the planets around the Sun. Nicholas strongly influenced Giordano Bruno by denying the finiteness of the universe and the Earth's exceptional position in it. He argued that as it was not the centre of the universe, it was equal in rank with the other planets. Space was boundless and the Sun and its planets were but one of any number of similar systems. There even might be other inhabited worlds with rational beings equal in power, or possibly superior, to ourselves. The Inquisition burnt Bruno at the stake for following Nicholas's teachings.

Nicholas's writings influenced the development of Renaissance mathematics and science. His first and most famous treatise, *De Docta Ignorantia* ('On Learned Ignorance' 1440), is a magnificent discourse on the finite and the infinite. This seminal work also contains various bold astronomical and cosmological speculations that depart entirely from traditional doctrines. He proposed not only that the Earth is not at the centre of the cosmos, but that it is not at rest and that its poles move. He also argued long before Kepler that the motions of the planets are not circular: '*It is impossible for the world machine to have this sensible earth, air, fire, or anything else for a fixed and immovable centre. For in motion there is no simply minimum, such as a fixed centre…And although the world is not Infinite, it cannot be conceived of as finite, since it lacks boundaries within which it is enclosed…Therefore, just as the earth is not the centre of the world, so the sphere of fixed stars is not its circumference.*'

NICHOLAS OF CUSA, KEPLER AND INFINITY

NICHOLAS OF CUSA'S work was the first modern discourse on the subject of the Infinite, the '*unqualifiedly Maximum*', beyond which '*there can be nothing greater*'. Nicholas said that the infinite is something that the mind can only approach through metaphor. Nicholas helped overthrow Aristotelian metaphysics, paving the way for Kepler. He simply swept aside existing Aristotelian cosmology based on perfect forms such as circles. In Nicholas's view, non-uniformity in shape and motion is the condition rendering the universe susceptible to knowledge. Because the human mind knows all things 'by relation', if motions and shapes were uniform or

‘perfect’, humankind would never be able to know the world. He maintained that all motion and substance in the material world must be non-uniform: ‘*Wherefore it follows, that, except for God, all positable things differ. Therefore, one motion cannot be equal to another; nor can one motion be the measure of another, since, necessarily, the measure, and the thing measured differ. Although these points will be of use to you regarding an infinite number of things, nevertheless, if you transfer them to astronomy, you will recognize that the art of calculating lacks precision, since it presupposes that the motion of all the other planets can be measured by reference to the motion of the Sun…And since no two places agree precisely in time and setting, it is evident that judgments about the stars are, in their specificity, far from precise…*’

Kepler stated that Nicholas was ‘*divinely inspired*’, and cited Nicholas’s insight regarding the difference between the ‘*Straight*’ and the ‘*Curved*’, that while ‘*an inscribed polygon grows more like a circle the more angles it has…even though the multiplication of its angles were infinite, nothing will make the polygon equal the circle unless the polygon is resolved into identity with the circle.*’ The straight and the curved represent incommensurable species of magnitude, so Nicholas came to his conclusions that the universe was infinite, with no centre, and an infinite number of stars and planets.

Because the cosmos is infinitely large, Nicholas argued that it has no unique centre at all, since it can be equally viewed as centred about any point. He thus introduced the notion of spatial perspective into cosmological thinking: ‘*Since it always appears to every observer, whether on the earth, the sun, or another star, that one is, as if, at an immovable centre of things and that all else is being moved, one will always select different poles in relation to oneself, whether one is on the sun, the earth, the moon, Mars, and so forth. Therefore, the world machine will have, one might say, its centre everywhere and its circumference nowhere, for its circumference and centre is God, who is everywhere and nowhere.*’ The universe of Nicholas was not a heliocentric cosmos with finite size, but a centreless cosmos whose size is infinite.

INNOVATIVE MACHINES

— 1495 —

LEONARDO DA VINCI 1452–1519, FLORENCE, MILAN AND ROME, ITALY

Leonardo da Vinci has been called ‘the universal genius par excellence’. He could move easily between mastery of painting, architecture, anatomy, sculpture, music, geometry, science and engineering. Advances in engineering, hydrodynamics, optics, civil engineering and anatomy have been attributed to him. Leonardo consulted on architecture in Venice from 1495–9, became a military engineer for Cesare Borgia, and then returned to Florence, where he painted the *Mona Lisa*. Artists and craftsmen in Leonardo’s time knew how to build and repair familiar kinds of machines, but the idea of inventing new kinds of machines would not have occurred to them. However, the establishment by Filippo Brunelleschi (1337–1446) of the laws of linear perspective around 1425 gave Leonardo and others a powerful instrument to depict mechanical devices in a realistic manner. Leonardo set out to write the first systematic explanations of how machines work, and how various elements of machines can be combined. He reasoned that by understanding how each separate machine part worked, he could modify them and combine them in different ways to improve existing machines, or create inventions no one had ever seen before.

ROBOTS TODAY

ROBOTS WERE known as ‘automata’. The term robot dates to 1921 when the Czech playwright Karel Capek referred to poor serfs as ‘robots’ in his play *R.U.R* (*Rossum’s Universal Robots*). Eventually they cause unemployment and lead to the collapse of society. Nine decades after Capek’s vision, the rise of the robot has gathered pace, and these machines are now capable of performing a wide variety of jobs ranging from building cars to performing delicate brain surgery.

Half a millennium after he wrote his *Notebooks*, many of the sketches in his surviving 13,000 pages of notes and technical drawings can be used as blueprints to create perfect working models. Leonardo’s journals include depictions of a vast number of inventions and ideas, including the tank, hang glider, calculator, helicopter, engines, double hull, solar power, flying machines, musical instruments, hydraulic pump, parachute, finned mortar shell, steam cannon and reversible crank mechanisms. His *Notebooks* reveal the richness of Renaissance technology that spawned the Scientific Revolution. His treatment of light in paintings such as the *Mona Lisa* and *The Virgin of the Rocks* changed forever the way in which artists perceived the medium and used it in their paintings.

Among his inventions that have passed into general practical use are the lens-grinding machine, a machine for testing the tensile strength of wire and the automated bobbin winder. His study of human anatomy led to the design of the first known robot around 1495, the humanoid automaton now known as *Leonardo’s Robot*. Its design notes were rediscovered in the 1950s – Leonardo had displayed it to Duke Sforza at his court in Milan shortly before he painted *The Last Supper*. Operated by a series of pulleys and cables, the robot knight could stand, sit, raise its visor and independently manoeuvre its arms. A mechanism in its chest gave power and control for the arms, while the legs were powered by an external crank mechanism. Rebuilt according to the design, it is fully functional. Al-Jazari has also been credited with making the first automata.

HOW THE SOLAR SYSTEM WORKS

—— 1543 ——

NICOLAUS COPERNICUS 1473–1543, FRAUENBERG (FROMBORK) CATHEDRAL, POLAND

Born in Poland, after studying in Cracow and Italy, Copernicus spent the rest of his life as a canon in Frauenberg Cathedral in the north of the country. This founder of modern astronomy proved that the Sun was the centre of our solar system, in the process severely weakening the power of the Catholic Church. His investigations in astronomy were carried on quietly and in solitude, without help or consultation. Copernicus made his celestial observations from a turret on the protective wall around the cathedral, 100 years before the invention of the telescope. In 1530, Copernicus completed his great work *De Revolutionibus Orbium Coelestium* ('On the Revolutions of the Celestial Spheres'), which asserted that the Earth rotated on its axis once daily and travelled around the Sun once a year. Until Copernicus the Western world believed in Ptolemaic theory – that the universe was a closed space bounded by a spherical envelope of fixed stars, beyond which there was nothing.

BILL GATES AND THE LEONARDO DA VINCI BUSINESS

THE *Codex Leicester* is a collection of largely scientific writings by Leonardo da Vinci, named after the Earl of Leicester, who purchased it in 1717. It is the most famous of Leonardo's journals, and was bought in 1980 by the industrialist Armand Hammer. In 1994, American business magnate Bill Gates bought it at an auction for $30.8 million, making it the most expensive book ever sold, and he subsequently renamed it the *Codex Leicester*. The codex is put on public display once a year in a different city around the world, and may now be worth around $100 million.

Ptolemy's cosmology argued that the Earth was a fixed, inert, immovable mass, located at the centre of the universe, and all celestial bodies, including the Sun and the fixed stars, revolved around it. It was a theory that appealed to human nature, and especially the church, which believed that the Earth and its people were created and looked over by God. Copernicus's hypothesis that the Sun was the centre of the solar system was not new, as Artistarchos had proposed this, but contemporary astronomers

still believed in the Aristotelian/Ptolemaic geocentric or Earth-centred model. We know that Copernicus was aware of Aristarchos's work, since his original draft of *De Revolutionibus* has survived. It features a passage referring to the Greek which Copernicus crossed out so as not to compromise the originality of his theory. Copernicus knew that each planet's orbital period was related to the Sun's year. The planets were placed in their correct order around the Sun, with the Moon held in orbit around the Earth. Nicholas of Cusa believed that anywhere would be the centre of the universe, as it was infinite. It may be that Copernicus was afraid to concur with him, believing that it would be easier to convince the Church that our solar system was the centre of all things.

However, Copernicus was the first person in history to create a complete integrated solar system, combining mathematics, physics and cosmology, whereas Ptolemy had treated each planet separately. Copernicus delayed publishing his findings, probably for fear of the reaction of the church leaders, and constantly revised it for around 30 years. However, parts of his work were circulated among a few astronomers. Georg Joachim von Lauchen (Rheticus) was a 25-year-old German mathematics professor who sought out the 66-year-old cleric, having read one of his papers. Intending to stay as a house guest for two weeks, Rheticus actually stayed for two

years, and persuaded Copernicus that it was right to publish. Rheticus published a summary of Copernicus's findings in 1539, and the complete *De Revolutionibus* in 1543, the year of Copernicus's death. Copernicus was never to know what a controversy his work caused. Copernicus's system was taught in some universities in the 1500s but did not permeate the wider academic world until approximately 1600. The Italian scientists Galileo and Bruno were arrested by the Holy Inquisition for their beliefs in a heliocentric cosmos, with Bruno being burnt at the stake for heresy. With Tycho Brahe's later observations, allied to the mathematics of Kepler's laws of the motion of planets and Newton's laws of gravitational attraction and dynamics, Copernican theory evolved into the understanding of the laws of celestial mechanics. *De Revolutionibus* was placed on the Vatican Index of proscribed books in 1616 and only removed in 1835.

WHAT BECAME OF OUR EDEN?

'*OF ALL discoveries and opinions, none may have exerted a greater effect on the human spirit than the doctrine of Copernicus. The world had scarcely become known as round and complete in itself when it was asked to waive the tremendous privilege of being the centre of the universe. Never, perhaps, was a greater demand made on mankind – for by this admission so many things vanished in mist and smoke! What became of our Eden, our world of innocence, piety and poetry; the testimony of the senses; the conviction of a poetic – religious faith? No wonder his contemporaries did not wish to let all this go and offered every possible resistance to a doctrine which in its converts authorized and demanded a freedom of view and greatness of thought so far unknown, indeed not even dreamed of.*' Johann Wolfgang von Goethe, 1749–1832

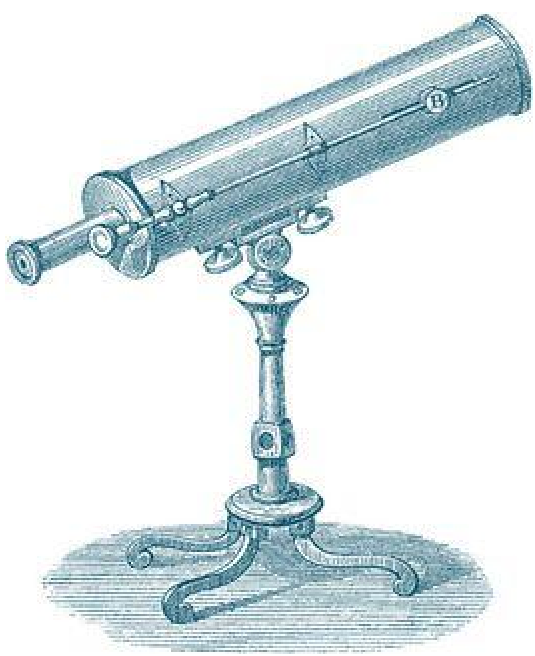
TELESCOPE AND THEODOLITE

—— *c* .1551 (*published* 1571) ——

LEONARD DIGGES 1520–1559, ENGLAND

The first of Leonard Digges's books, *The General Prognostication*, had been published in 1553, and expanded in 1555 as *A Prognostication of Right Good Effect*, then revised in 1556 as *Prognostication Everlasting*.

These books were extremely popular, enhancing Digges's reputation, partly because they were written in English when standard scientific publications were normally in Latin. The books were early almanacs with data about astronomy and astrology, calendars of church events and Moon motions for several years, information on timekeeping and weather phenomena and even instructions for bloodletting. This mathematician and surveyor was a great popularizer of science, and apparently invented both the refracting and reflecting telescopes. His son, the famous English astronomer Thomas Digges, wrote in the preface to Leonard Digges's posthumous surveying textbook *A Geometric Practice Named Pantometria*: '*He may wonderfully help him self, by Perspective glasses. In which (I trust) our posterity will prove more skilful and expert, and to greater purposes, than in these days, can (almost) be credited to be possible…my father by his continual pain-full practices* [practical experiments], *assisted with Demonstrations Mathematical, was able and sundry Times hath by proportional Glasses duly situate in convenient angles, not only discovered things far off, read letters, numbered pieces of money with the very coin and superscription thereof, cast by some of his friends of purpose upon Downs in open fields, but also at seven miles declared what had been done at that instant in private places…*'



Digges took part in the ill-fated Protestant rebellion in 1554, led by Sir Thomas Wyatt against England’s new Catholic Queen Mary. Digges was condemned to death, but had his sentence commuted, instead forfeiting all his property and estates. Penniless, he spent the rest of his life trying to regain his properties and reputation, dying in 1559. This probably explains why his telescope was not more widely recognized and popularized.

The German-Dutch lensmaker Hans Lippershey has been credited as being the first person to experiment with combining lenses to create crude telescopes and binoculars. While others later claimed to have invented the device, it was Lippershey who applied to the government of the Netherlands for a patent in 1608. It was denied, as the government thought that the device could not be kept a secret. In 1609, Galileo learned of Lippershey’s device and constructed his own telescope, eventually increasing the magnification to a factor of 20. By 1611, Johannes Kepler was using a telescope consisting of two convex lenses, which gave good magnification but an inverted image. In 1668 Isaac Newton is credited with inventing the reflecting telescope (instead of Digges), using a curved mirror rather than a large lens to collect and focus light, eliminating problems of chromatic aberration.

DIGGES AND THE THEODOLITE

IN AROUND 1551 Leonard Digges invented the theodolite, as well as inventing and improving a number of other instruments for use by surveyors, carpenters and masons. A theodolite is a precision instrument for measuring angles in the horizontal and vertical planes, mainly used for surveying. The first recorded occurrence of the word theodolite is found in his posthumous *Pantometria* of 1571.

EQUALS SIGN

—— 1557 ——

ROBERT RECORDE 1510–1589, TENBY, WALES

Robert Recorde was born in Tenby, Wales. His invention of the ‘equals’ sign (=) revolutionized algebra, and his mathematical works were translated and read all over Europe. Although a doctor of medicine at the English

royal court, he was more noted for his astronomy and mathematics. In 1551 Recorde wrote *Pathway to Knowledge*, which is considered to be an abridgement of Euclid's *Elements* and has been called a 'landmark in mathematical thought'. It is certainly the first English translation, in which Recorde rearranged Euclid's writings to make better sense. This was his only book that is not written in the form of a dialogue between a master and student. The year 1552 saw the publication of his *The Ground of Artes*, a book for learning arithmetic, dedicated to King Edward VI, his patron. The textbook had appeared in 26 editions by 1662, '*teaching the perfect work and practice of Arithmeticke etc.*' in Recorde's own words. It discusses Arabic numeral operations, counter computation, proportion, fractions and the 'rule of three', etc. His arithmetic book was notable in being innovative in two respects. Firstly, it was written as a dialogue between a master and pupil to keep it interesting, and secondly it used the device of pointing fingers at important points in the text (predating Windows icons by more than 300 years!).

Some time after this he wrote *The Gate of Knowledge*, a treatise upon measurement and the use of the quadrant which has been lost. He later spoke of a quadrant that he invented (whether for mensuration or for navigation is unknown), which is probably described in this lost book. In 1556 *The Castle of Knowledge* was published, dealing with the science of construction and the use of the sphere, using Ptolemaic astronomy, and mentioning Copernicus favourably (and dangerously for the time). In 1557 appeared *The Whetstone of Witte*, his textbook of elementary algebra. In this he invented the = sign using two parallel line segments, '*because no 2 things can be more equal*', and to '*avoid the tedious repetition of equals to*'. A mathematician, merchant, doctor of medicine, navigator, teacher, metallurgist, cartographer, inventor and astronomer, Recorde's textbooks and their translations were studied across the Western world.

COPERNICUS AND HERESY

COPERNICUS'S IDEAS were less than 20 years old, and were considered 'heretical' by the Church at this time, yet the allusion to him in the fourth treatise of Recorde's *The Castle of Knowledge* runs as follows:

'*Scholar: I perceive it well: for as if the Earth were always out of the centre of the world, those former absurdities would at all times appear: so if*

at any time the Earth should move out of his place, those inconveniences would then appear.

Master: This is truly to be gathered, howbeit, Copernicus, a man of great learning, of much experience, and of wonderful diligence in observation, has renewed the opinion of Aristarchus Samius, and affirms that the earth not only moves circularly about his own centre, but also may be, yea and is, continually out of the precise centre of the world 38 hundred thousand miles: but because the understanding of that controversy depends upon profounder knowledge than in this Introduction may be uttered conveniently, I will let it pass till some other time.'

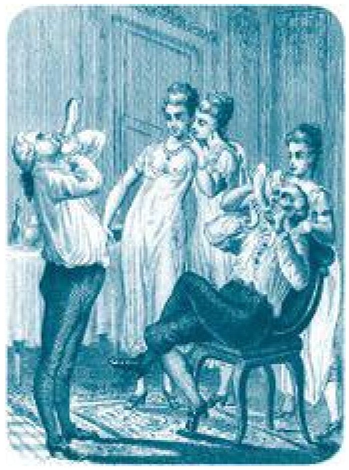
CONDOM

—— 1564 ——

GABRIELE FALLOPPIO (FALLOPIUS) 1523– 1562, MODENA, PISA AND PADUA, ITALY

Condoms have allowed generations of people to avoid unwanted pregnancies, and saved an inestimable number of lives by preventing the spread of diseases such as Aids. It appears that the Romans made condoms from goats' bladders, the Egyptians from linen sheaths, and the Japanese used leather and tortoiseshell. The Chinese wound oiled silk paper or lamb's intestine around the penis to prevent infection and pregnancy. Falloppio was professor of anatomy and surgery, as well as botany, at the university of Padua. His work dealt mainly with the anatomy of the head, and he added much to what was known about the internal structure of the ear, the eye and nose. Falloppio was the first to use an aural speculum for the diagnosis and treatment of diseases of the ear, and he published three treatises on surgery, ulcers and tumours. Falloppio also studied the reproductive organs of both sexes, and described the tube which leads from the ovary to the uterus and which now bears his name. He wrote the earliest description of condom use, published posthumously in 1564, *De Morbo Gallico* ('The French Disease', referring to syphilis). Falloppio recommended the use of a device he claimed to have invented. Linen sheaths were soaked in a solution of salt or herbs and allowed to dry before use. The cloths he described were sized to cover just the glans of the penis, and were held on with a ribbon. Falloppio claimed to have performed an

experimental trial of the linen sheath on 1100 men, reporting that none of them had contracted syphilis. Soon after, the Paduan clinician Hercules de Saxonia (Ercole Sassonia, 1551–1607) described a larger sheath, still made of linen, that covered the entire penis.



After the publication of *De Morbo Gallico*, the use of penis coverings spread throughout Europe. In addition to linen, condoms during the Renaissance period were made out of intestines and bladders. Cleaned and prepared intestine had been sold for use in glove-making since at least the 13th century. The first indication that these devices were used for birth control, rather than disease prevention, is the 1605 disapproval expressed by a Catholic theologian. In 1666, the English Birth Rate Commission attributed a downward fertility rate to use of *condons*, the first documented use of that word (or any similar spelling). The origin of the word is debatable. The earliest known condoms made from animal gut, dating to before 1648, were discovered in a garderobe in Dudley Castle. The Dutch began exporting 'fine leather' condoms to Japan. In those days condoms were used more than once, and they can be seen in the backgrounds of contemporary paintings hanging up on hooks to dry, ready for the next use. By the 18th century specialist condom shops were in evidence across Europe. In London, Mrs Phillips and Mrs Perkins promoted their rival wares in pamphlets, while 'Miss Jenny' specialized in washed, second-hand condoms. Condoms were now available in a variety of qualities and sizes, made from linen treated with chemicals or from the tissues of bladder or intestine softened by treatment with sulphur and lye.

'THE FRENCH DISEASE'

THE FIRST well-documented outbreak of what we know as syphilis occurred in 1494 in the French army. The disease then swept across Europe in 1495 – '*its pustules often covered the body from the head to the knees, caused flesh to fall from people's faces, and led to death within a few months'*. By 1505, the disease had spread to Asia, and within a few decades had reportedly *'decimated large areas of China'*.

Syphilis was commonly known as 'the great pox' in the 15th century, and the variola virus was called 'the small pox' to differentiate it. Syphilis was called the 'French disease' in England, Italy and Germany, and the 'Italian disease' in France. The Dutch called it the 'Spanish disease', and the Russians called it the 'Polish disease'. The Turks called it the 'Christian disease' and the Tahitians the 'British disease'. The national names are due to the disease often being spread by foreign sailors during unprotected sexual contact with local prostitutes. In its early stages, the 'great pox' produced a rash similar to smallpox but smallpox was a far more deadly disease.' Untreated, the death rate from syphilis was between 8 per cent and 58 per cent, and that from smallpox from 20 per cent to 60 per cent (with over 80 per cent of cases occurring in children).

Condoms were expensive until 1839 when Charles Goodyear discovered the process of vulcanization of rubber. This makes rubber, which is naturally hard when cold and soft when warm, elastic. This enabled condoms to be made from rubber, but the first rubber condoms were as thick as bicycle tyre inner tubes and had big seams down the sides. In 1844 mass-production began. Soon a manufacturing method was developed that removed the need for a seam, creating what we regard as the modern-day condom. They were washable and reusable. In 1861, the first advertisement for condoms was published in an American newspaper when *The New York Times* printed an advertisement for *Dr. Power's French Preventatives*. The introduction of latex in 1912 made condoms cheap and disposable, and the single-use condom was born. By the Second World War, latex condoms were being mass-produced and were distributed to troops all over the world. In the 1950s, the latex condom was improved by making it thinner, tighter and treated with lubrication. Also the reservoir tip was introduced; this collects semen in the end, decreasing the risk of leakage and thus

unintentional pregnancy. The latex condom is still the most popular type, despite the advent of the plastic condom, but any condom is still colloquially called a ‘rubber’. With the arrival of the birth-control ‘pill’ in the 1960s, and better antibiotics to treat venereal disease, condom sales fell. However, the discovery of the Human Immunodeficiency Virus (HIV) and Acquired Immune Deficiency Syndrome (AIDS) have given a new lease of life to the product. Around 6–9 billion condoms are said to be used each year, but there are no reliable statistics.

DEPICTION OF A ROUND EARTH ON A FLAT MAP

—– 1569 —–

GERHARDUS MERCATOR 1512–1594, FLANDERS, HOLY ROMAN EMPIRE (HOLLAND)

After producing several maps, the Flemish mathematician Mercator (originally Gerard de Kremer) was appointed court cosmographer to the duke of Jülich-Cleves-Berg in 1564. He knew that mariners had no dependable nautical charts. Compass bearings were contrary to chart indications, so on a long voyage ships had to approach land and use coastal features to estimate exactly where they were. No-one could truly represent the globe on a flat plane, to be of navigational use on ships. In 1569 Mercator found the solution, projecting the world onto a cylinder. His *Mercator Projection* world map had the parallel lines of latitude and meridians of longitude intersecting each other perpendicularly, and stretched the distances on the parallels by the same factor as was applied to the distances on the meridians.

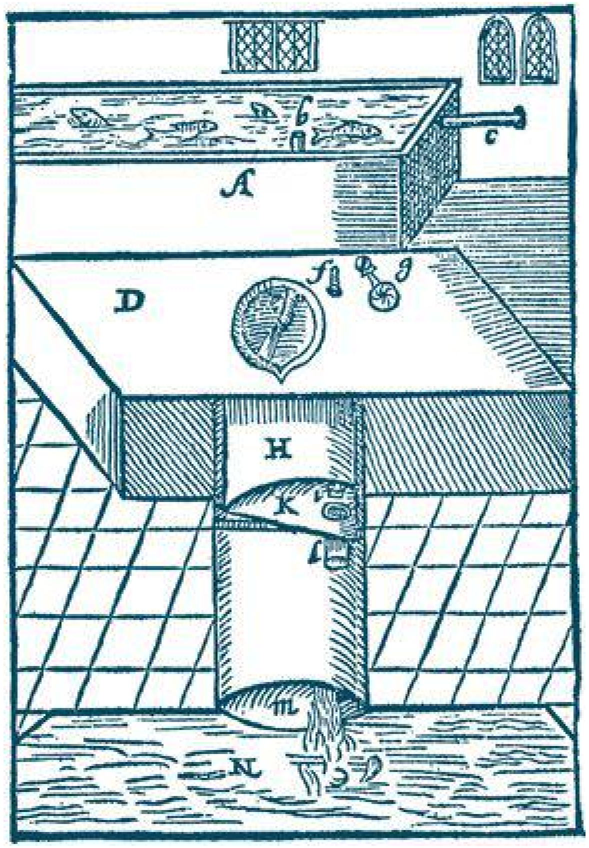
All lines of constant bearing (called *rhumb lines* or *loxodromes* – curves which cut every meridian at the same angle) are represented by straight segments on a Mercator map. This is exactly the type of route employed by ships at sea, where compasses are used to indicate geographical directions and to steer the ships. When Mercator presented his new cylindrical projection world map, he immediately solved one of the two most urgent problems of navigation, drafting a map on which a rhumb can be represented as a straight line. (The other was a method of determining longitude, see John Harrison, 1735). Two properties, conformality (preserving oriented angle between curves) and straight rhumb lines, made Mercator's projection uniquely suited to marine navigation. Compass courses could be marked as straight lines, and a ship's courses and bearings would be measured using 'wind roses' or protractors. (A wind rose is a graphic device which gives a view of how wind speed and direction are typically distributed at a particular location.) The deviation from the compass course could be measured and the course adjusted, using a parallel ruler or a pair of navigational compasses. Apart from being the first man to show a round Earth on a flat map, Mercator was the first person to use the terms of North and South America, and the first to depict the New World as stretching from the northern to the southern hemisphere. Mercator was also the first man to use the term *atlas* for a collection of maps, '*to honour the Titan, Atlas, King of Mauritania, a learned philosopher, mathematician, and astronomer.*' The Mercator projection revolutionized world trade and exploration. When the problem of measuring longitude at sea was solved, ocean-going navigation and world trade grew exponentially.

FLUSH TOILET

— *c*.1584 —

JOHN HARINGTON (ALSO HARRINGTON) 1561–1612, BATH, ENGLAND

Before the flush toilet, and the consequent need for sewage disposal systems, human waste was simply emptied into the streets, at great risk to public health. The flush toilet disposes of waste by using water to flush it through a drainpipe to another location. Modern toilets incorporate an S-, U-, J- or P-shaped bend, which causes the water in the toilet bowl to collect and act as a seal against sewer gases. Since flush toilets are typically not designed to handle waste on site, their drain pipes must be connected to waste conveyance and waste treatment systems. Until the mid-20th century, flush toilets were called water closets (WCs). Harington was a courtier at Queen Elizabeth I's court, known as her *saucy Godson*. However, because of his insalubrious poetry, translations and other writings, he fell in and out of favour with the Queen, as well as with her successor, James I. The work for which he is known today, *A New Discourse of a Stale Subject, called the Metamorphosis of Ajax* (1596) is a political allegory, a coded attack on the *stercus* or excrement that was poisoning society with torture and state-sponsored libels against his relatives. Because of its allusions directed against the queen's favourite, the Earl of Leicester, Harington was banished from court and later was imprisoned.



Harington invented Britain’s first flushing toilet, also called the Ajax, *jakes* being an old word for toilet. The slang term *jacksy* is sometimes still heard today. It was installed at his manor in Kelston near Bath which he built between 1584 and 1591. Queen Elizabeth temporarily forgave him for his slanders, and visited his house at Kelston in 1592. There are conflicting reports about whether the queen used his new invention, or ordered one for her palace at Richmond. Harington’s water-closet had a pan with an opening at the bottom, sealed with a leather-faced valve. A system of handles, levers and weights poured in water from a cistern, and opened the valve while cleaning the bowl. However, the public carried on using chamber pots, which were usually emptied from an upstairs window into the street below. Alternatively, in cities *night soil* collectors gathered buckets of human waste at night from toilets and cess-pits. This was then thrown into streams or used as fertilizer, causing illness and sometimes epidemics as a consequence.

In 1738, a valve-type flush toilet was invented by J.F. Brondel. In 1775 a flushing water-closet was first patented by an Alexander Cummings of London. This was a device similar to Harrington's Ajax. His S-trap is still in use today, using standing water to seal the outlet of the bowl, preventing the escape of foul air from the sewer. The design had a sliding valve in the bowl outlet above the trap. In 1848 a Public Health Act ruled that every new house should have a '*water closet, privy, or ash-pit*'. An early water closet was exported from England to Queen Victoria's palace at Ehrenburg, Germany, but, to maintain protocol, she was the only person allowed to use it.

In the 1880s the plumber and sanitary engineer Thomas Crapper, inventor of the floating ball-cock, popularized the siphon system for emptying the tank, replacing the earlier floating valve system which was prone to leaks. In 1885 pottery manufacturer Thomas Twyford built the first one-piece ceramic toilet using a flush-out siphon design.

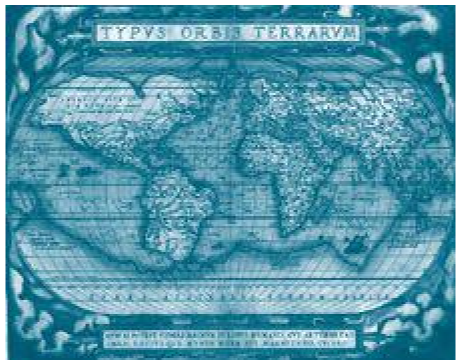
CONTINENTAL DRIFT

—— 1596 ——

ABRAHAM ORTELIUS 1527–1598, ANTWERP, THE LOW COUNTRIES (NOW BELGIUM)

Ortelius (Abraham Ortels) was the first to propose how continents are formed. Ortelius had been influenced by Mercator to become a scientific geographer. At Mercator's prompting, he produced the first modern atlas, in 1564, an eight-leaved map of the world. It was reproduced as part of the 53 maps in *Theatrum Orbis Terrarum* ('Theatre of the World') in 1570. This is considered to be the first true modern atlas. In 1575 Ortelius was appointed

geographer to Philip II of Spain, and he produced a work on ancient geography, *Synonymia Geographica* in 1578. It was expanded as *Thesaurus Geographicus* in 1587, and in another expanded edition in 1596 he proposed a theory of *Continental Drift* writing that the Americas were '*torn away from Europe and Africa…by earthquakes and floods…The vestiges of the rupture reveal themselves, if someone brings forward a map of the world and considers carefully the coasts of the three* [continents].'



OVER THREE CENTURIES LATER

THE GERMAN geophysicist and meteorologist Alfred Lothar Wegener (1880–1930) proposed the theory of continental drift (*Kontinentalverschiebung*) in 1912. He stated that the continents were slowly drifting around the Earth. In 1915, he wrote in *The Origin of Continents and Oceans* that there had once been a giant continent, which he attempted to prove scientifically. He died on an expedition to Greenland in 1930. However, the latest edition of his work, published just before he died, demonstrated that shallower oceans were geologically younger than deeper ones. Like Ortelius, Wegener was ignored. In 1953 British scientists using paleomagnetic techniques found that India had originally been in the Southern Hemisphere, as Wegener had predicted. The discovery of *seafloor spreading* helped explain how continental drift might occur; it was part of the 1960s development of *plate tectonics theory*. This process happens at mid-ocean ridges, when new oceanic crust is formed through volcanic activity, and then gradually moves away from the ridge. Plate tectonics reveals the formation and movement of continents, via eight major plates on the Earth's crust pressing against each other. These plates are in constant motion travelling at a few inches per year, and ocean floors are continually

moving. Convection currents, driven by radioactive decay deep inside the Earth, move the plates in different directions. At the boundaries of the plates, there are frequent earthquakes, and the formation of volcanoes, mountains, mid-ocean ridges and oceanic trenches. At last, Wegener's work was accepted by the scientific community. He is now recognized as the founding father of one of the major scientific revolutions of the 20th century.

MAGNETISM

–– 1600 ––

WILLIAM GILBERT (GILBERD) 1544–1603, LONDON, ENGLAND

Credited by many as the father of electricity and magnetism, Gilbert helped to prove that the Earth was not the centre of the universe. To aid navigation, Gilbert tried to clarify his understanding of the compass and the phenomenon of magnetism. To prove his hypothesis regarding the magnetism of the planet, Gilbert conducted 17 years of experiments, this being one of the first examples of what we now call the experimental scientific method. The revolutionary new concept of using experimentation to support one's hypothesis radically changed the course of science, ushering in an entirely new age of scientific theory, exploration and discovery. Gilbert collaborated with ships' captains, navigators and compass makers, performing elaborate experiments using a spherical magnetic lodestone and a freely moving needle. He discovered that it was possible to create magnets from ordinary metals by rubbing them with a magnet. Gilbert also learned how to strengthen magnets, and he noticed that magnets lost their power when exposed to extremely high temperatures. When he observed that magnetic forces often produced circular motions, he began to connect the phenomenon of magnetism with the rotation of the Earth. This led to his discovery of the Earth's own magnetism, and provided the theoretical foundation for the science of geomagnetism. In 1600 he became president of the Royal College of Physicians, and served as physician to Elizabeth I and to her successor James I. Also in 1600, his *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* ('On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth') was

quickly accepted throughout Europe as the standard work on electrical and magnetic phenomena.

GILBERT AND GARLIC

ACCORDING TO Dr David P. Stern of NASA: ‘*William Gilbert was fascinated by magnets. Britain was a major seafaring nation in 1588 when the Spanish Armada was defeated, opening the way to British settlement of America. British ships depended on the magnetic compass, yet no one understood why it worked. Did the pole star attract it (as Columbus once speculated), or was there a magnetic mountain at the pole, which ships should would never approach, because the sailors thought its pull would yank out all their iron nails and fittings? Did the smell of garlic interfere with the action of the compass, which is why helmsmen were forbidden to eat it near a ship’s compass? For nearly 20 years William Gilbert conducted ingenious experiments (among others, making sure that garlic had no effect on compasses) to understand magnetism. Until then, scientific experiments were not in fashion: instead, books relied on quotes of ancient authorities that was where the myth about garlic started.*’

Gilbert overturned many popular scientific theories, becoming the first person to fully explain the workings of a magnetic compass and the first to research the properties of the lodestone (magnetic iron ore). He distinguished between magnetism and static (known as the *amber effect*).

Gilbert's findings suggested to him that magnetism was the 'soul' of the Earth, and that a perfectly spherical lodestone, when aligned with the Earth's poles, would spin on its axis, just as the Earth spins on its axis over a period of 24 hours. Gilbert disagreed with the traditional cosmologists' belief that the Earth was fixed at the centre of the universe, preparing the way for Galileo. Rejecting this established belief of geocentrism, he further proposed that Earth was a magnetic planet, with polarity corresponding to its North and South poles. For the next 200 years *De Magnete* was the most important treatise on the subject of magnetism. Gilbert was the first to use the terms *magnetic pole*, *electric force* and *electric attraction*. Gilbert was also the first to clearly distinguish between magnetic and electrical forces. The word *electricity* was coined by Gilbert, who based it on the Greek word for amber. While not attributing magnetism to attraction among the stars, Gilbert pointed out 20 years before Galileo that the motion of the stars in the sky was due to Earth's rotation, and not the rotation of the spheres. Gilbert made the first attempt to map the surface markings on the Moon in the 1590s. His chart, made without the use of a telescope, showed outlines of dark and light patches that appeared on the Moon's face. A unit of magnetomotive force, the magnetic potential, was named the *gilbert* after him.

EXPERIMENTAL SCIENTIFIC METHOD

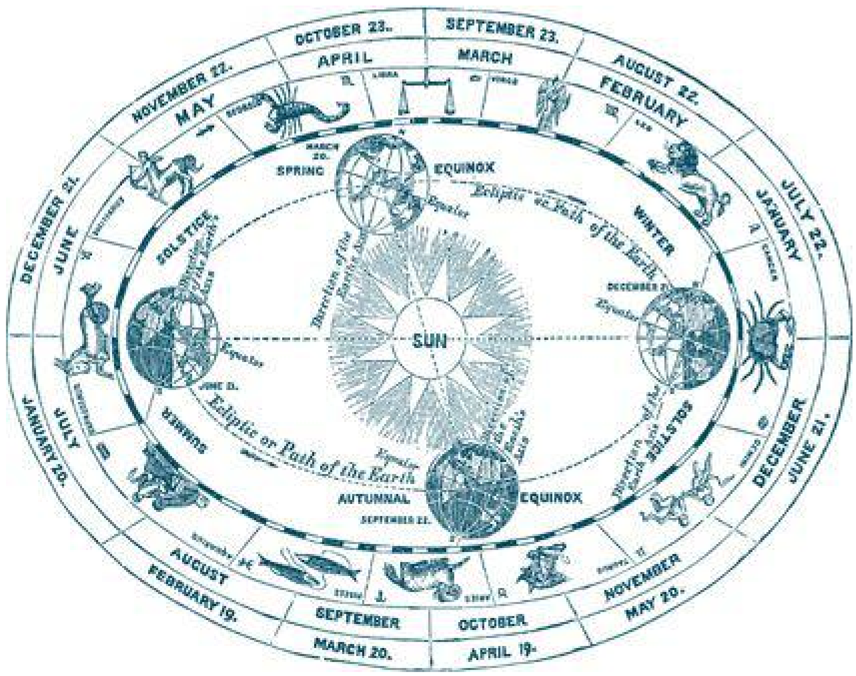
—– 1602 —–

GALILEO GALILEI 1564–1642, PISA AND PADUA, ITALY

'The father of modern astronomy' pioneered the *experimental scientific method*. Like William Gilbert, Galileo was one of the first scientists to use the results from experiments as evidence for a scientific theory. He experimented with pendulums and formulated the *law of the pendulum* in 1602. He found that the *period* (the time during which a pendulum swings back and forth) does not depend on the arc of the swing (the *isochronism*). Eventually, this discovery would lead to Galileo's further study of time intervals and the development of his idea for a pendulum clock, leading to the manufacture of more effective clocks. In 1609 Galileo learned of the invention of the telescope in Holland and he constructed a much superior model in 1610, with a more powerful magnification of 20 times. He did not

invent the telescope, but was the first to give it that name. Galileo was the first man to use a refracting telescope to make important astronomical discoveries, including the four largest moons of Jupiter (now called the *Galilean moons*). This indisputable discovery of celestial bodies orbiting something other than Earth was a hammer blow to the 'Ptolemaic world system', the geocentric theory which held that everything in the universe orbited the Earth. Galileo also discovered that the *phases of Venus*, changes in light as Venus orbits around the Sun, were like the lunar phases that we all see. (Each month we experience the change from a darkened Moon through half Moon to full Moon.) The cycle of Venus happened every 528 days, and Galileo confirmed that Venus orbited the Sun, not the Earth. He was also the first Westerner to discover sunspots, in 1613, and he deduced that the Milky Way galaxy was made up of a multitude of individual stars.

As professor of astronomy at Pisa and then Padua, Galileo was required to teach the accepted theory that the Sun and all the planets revolved around the Earth. However, Galileo's observations with his new telescope convinced him of the truth of Copernicus's Sun-centred (heliocentric) theory. Galileo was not the first person to study sunspots, as the Chinese had known about them since about 90 BCE. However, it helped the Copernican case since Aristotle and Ptolemy thought that the heavenly bodies were smooth. Galileo wrote to Johannes Kepler supporting Copernicus, and also promoted Copernicus's theory in his 1613 book on sunspots. In 1614, Galileo was accused of heresy for his support of the Copernican theory, and in 1616, he was forbidden by the church from teaching or advocating these theories. The Catholic church also responded quickly to the 1632 publication of his *Dialogue Concerning the Two Chief World Systems* in which Galileo supported Copernicus. The Inquisition convicted him of heresy, forcing him to recant his support of Copernicus. His *Dialogue* was placed on the Vatican's *Index Librorum Probibitorum* (its blacklist of banned books.) He had written '*I do not feel obliged to believe that same God who endowed us with sense, reason, and intellect had intended for us to forgo their use.*' Because of his ill health and his age, Galileo was allowed to serve out his sentence under house arrest in a villa near Florence.



Also in his 1632 book, Galileo anticipates Newton by proposing *Galilean invariance* or *Galilean relativity*, a principle of relativity which states that the fundamental laws of physics are the same in all *inertial frames*. Galileo uses the example of a ship sailing at a constant velocity, without rocking, on a smooth sea. Any observer carrying out experiments below the deck would not be able to tell whether the ship was moving or stationary. In physics, the principle of relativity is the requirement that the equations describing the laws of physics have the same form in all admissible frames of reference, and Galileo was the first to explicitly state the principle.

Despite his ill health and house imprisonment, Galileo managed to finish his *Discourse on Two New Sciences* which was published in 1638. In this new book, he provided a mathematical proof of his theory of motion and a study of the tensile strength of materials. Aristotle had believed that if two objects of different mass were dropped at the same time, the heavier one would hit the ground first. Galileo reasoned that if two bricks of the same size and mass were dropped at the same time, they would hit the ground at the same time. He also reasoned that it would not make any difference in the speed the bricks fell, if the two bricks were glued together. Thus, the two glued bricks would fall at the same rate as a third brick which had the same size and mass as the first two. If this were true, then it did not make any difference how heavy two objects were, as they would both fall at the same rate if they were not acted upon by air resistance. This was Galileo's

law of falling bodies of 1638. It stated that '*Assuming that no air is present to act on the objects being dropped, under the influence of gravity alone, all bodies fall with equal acceleration, regardless of size, mass, density, or horizontal velocity.*'

THIRTEEN YEARS TO ACCEPT THAT THE EARTH MOVES AROUND THE SUN

FROM 1613, for 366 years, Galileo's finding that the Earth moved around the Sun was proscribed by the Vatican. In 1979, Pope John Paul II declared that the Roman Catholic church may have been mistaken in condemning Galileo, and established a commission to study the case. The commission moved at a glacial pace, and only delivered its findings in 1992. Pope John Paul II then lifted the *Edict of the Inquisition* from Galileo.

Some scientists disagreed until Galileo's theory was proven when the air pump (to make a type of primitive vacuum) was invented in 1650. A coin and a feather were both dropped at the same time in an evacuated tube and they touched the floor at the same time. (The vacuum helped negate the air resistance, or any effect of wind, on the feather). Many of us remember the story that Galileo was supposed to have dropped objects off the Leaning Tower of Pisa to prove his findings, but there is no proof of this ever happening. Furthermore, he was under house arrest at this time. By now, Galileo was completely blind, and had to dictate his findings to assistants. Galileo's work, and the empirical method by which he approached problems, opened the way for more research in physics, which eventually led to modern mathematical physics. *Two New Sciences* anticipated Newton's *Laws of Motion*, and Albert Einstein called Galileo '*the father of modern physics…indeed, of modern science*'.

LAWS OF PLANETARY MOTION

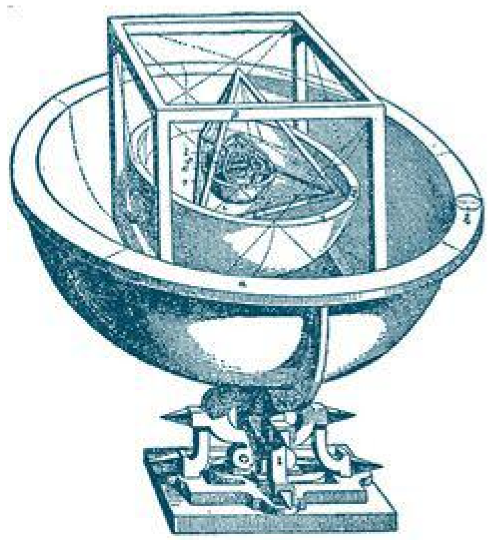
—— 1602–1618 ——

JOHANNES KEPLER 1571–1630, GRAZ, LINZ AND PRAGUE, HOLY ROMAN EMPIRE

A key figure in the Scientific Revolution, Kepler's laws provided a foundation for Isaac Newton's *theory of universal gravitation*. Born near

Stuttgart, this mathematician and astronomer proved that the Earth and planets travel about the Sun in elliptical orbits, and gave us the three fundamental laws of planetary motion. Although his astronomy teacher Michael Maestlin at university was forced to teach him the Ptolemaic world system, in private Maestlin told his graduate students of Copernicus's heliocentric theory. In 1597 Kepler published his first important work, *Mysterium Cosmographicum* ('The Cosmographic Mystery'), in which he argued that the distances of the planets from the Sun in the Copernican system were determined by the five regular solids, if one supposed that a planet's orbit was circumscribed about one solid and inscribed in another. Except for Mercury, Kepler's construction produced remarkably accurate results. The so-called Platonic solids occur in nature as crystals, being the polyhedrons known as the tetrahedron, cube, octahedron, dodecahedron and icosahedron. In Kepler's time only five planets were known and he tried for a decade to prove Pythagoras's hypothesis that there was a match between these five polyhedra and the sizes of the five planets' orbits. Pythagoreans believed that there was an intrinsic harmony between the regular polyhedra and the planetary orbits.

Because of his talent as a mathematician, in 1600 Kepler was invited to Prague by Tycho Brahe to become his assistant and to calculate new orbits for the planets from Brahe's observations. Brahe died in 1601 and Kepler was appointed his successor as imperial mathematician, the most prestigious appointment in mathematics in Europe. In 1604 Kepler published *Astronomia pars Optica* ('The Optical Part of Astronomy'), in which he discussed atmospheric refraction, lenses and gave a modern explanation of the workings of the eye. In 1606 he published *De Stella Nova* ('Concerning the New Star') on the new star (a supernova) that had appeared in the sky in 1604.



In 1609 his *Astronomia Nova* (‘New Astronomy’) appeared, and this contained Kepler’s first two laws. Kepler had tried to calculate the entire orbit of Mars, assuming an egg-shaped orbit, but after 40 attempts he realized in 1605 that it was an elliptical orbit. He immediately formulated what we know as his first law, which stated that: ‘*All planets move in ellipses, with the Sun at one focus*’. In 1602, he had formulated what came to be known as his second law, ‘*Planets sweep out equal areas in equal times*’, or ‘*a line joining a planet and the Sun sweeps out equal areas during equal intervals of time*’. In 1610 Kepler heard about Galileo’s discoveries with his new ‘spyglass’ (telescope). Kepler quickly composed a long letter of support which he published as *Dissertatio cum Nuncio Sidereo* (‘Conversation with the Sidereal Messenger’). Later that year, now with the use of a suitable telescope, Kepler published his observations of Jupiter’s satellites (the ‘Galilean moons’), thereby giving enormous support to the beleaguered Galileo. In 1613, Kepler demonstrated that the Christian calendar was in error by five years, and that Jesus had been born in 4 BCE, a conclusion now almost universally accepted.

In 1619 Kepler published his greatest work *Harmonices Mundi* (‘Harmony of the World’), in which he derived the heliocentric distances of the planets and their periods from considerations of musical harmony. In this work we find his third law formulated in 1618, relating the periods of the planets to their mean orbital radii: ‘*The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit*’ or ‘*the square of the periodic times are to each other as the cubes of*

the mean distances.' The established church had already accused Galileo of heresy in 1614, but it dared not attack the new Holy Roman Emperor Matthias's imperial mathematician. Therefore it targeted his mother, who in 1615 was accused of being a witch and imprisoned under threat of torture. Kepler spent a great deal of time away from his research, as he had to cope with a state of continuous war, a dispute over his dead wife's estate, and his three children falling ill with smallpox, one son dying. Eventually he managed to get his mother out of prison after he successfully defended her in court. She was freed in 1621. During the turmoil of the Thirty Years War, Kepler had his *Tabulae Rudolphinae* ('Rudolphine Tables') printed (1627), These were based on Tycho Brahe's accurate observations, and calculated according to Kepler's elliptical astronomy.

GOLDILOCKS PLANETS

NAMED AFTER the great astronomer, Kepler is a NASA spacecraft designed to discover Earth-like planets orbiting other stars. It was launched in March 2009, with a planned mission lifetime of at least 3.5 years. In particular, its mission is to discover Earth-size and larger planets in or near the *habitable zone*, the so-called *Goldilocks Planets*. The habitable zone is the distance from a star where an Earth-type planet can maintain liquid water on its surface, and thus possibly Earth-like life. It should be within a planetary system in a galaxy, with the stellar conditions required for maintaining carbon-based life. The name *Goldilocks Planet* comes from the story of *Goldilocks and the Three Bears*. The heroine Goldilocks chooses from sets of three items, ignoring the ones which are too extreme (too large or too small, too hot or too cold, etc.), settling on the one in the middle,

which is ‘just right’. A Goldilocks Planet for instance will not be too near or too far from a star to rule out liquid water on its surface.

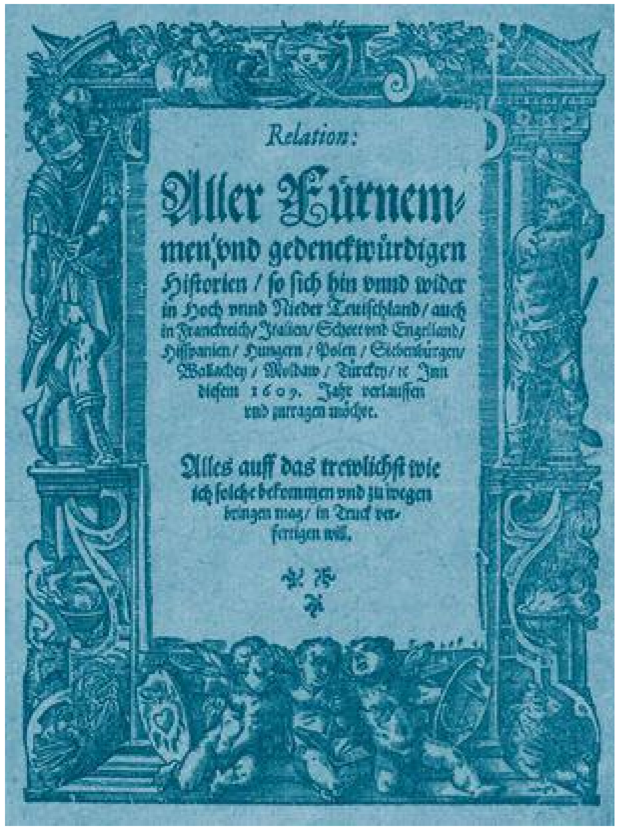
It is estimated by NASA that ‘*within a thousand light-years of Earth*’, there are at least 30,000 habitable planets. The Kepler team has estimated that there are ‘*at least 50 billion planets in the Milky Way*’, of which at least 500 million are in the habitable zone. In March 2011, NASA astronomers reported that about 1.4–2.7 per cent of all Sun-like stars are expected to have Earth-like planets within their habitable zones, so there are around two billion of these *Earth analogs* in our own Milky Way galaxy alone. Based on the Kepler data, an estimate of around 100 million habitable planets in our galaxy may be realistic. The astronomers also noted that there are 50 billion other galaxies, potentially yielding more than one sextillion (10 to the power of 21) *Earth analog* planets if all galaxies have similar numbers of planets as the Milky Way. These numbers of Goldilocks Planets far surpass what was originally thought, and statistically suggest that there must be life forms elsewhere in the universe.

NEWS PAPER

—— 1605 ——

JOHANN CAROLUS 1575−1634, STRASBOURG, HOLY ROMAN EMPIRE (NOW IN ALSACE, FRANCE)

With the invention of the newspaper, political news could quickly reach the masses, and the medium allowed for the wide dissemination of state propaganda, for instance, to argue the case for war and buoy up a nation’s morale. In the wealthy free city of Strasbourg, Carolus made a living by producing handwritten newsletters for rich subscribers. In 1604 he bought a workshop from a dead printer’s estate, and installed it in his house. Copying newsletters by hand was taking too much time, so he decided in 1605 to switch to printing them. Carolus thought that he could earn more money by printing, with a higher circulation selling at a lower price, as there was a rising demand for up-to-date information. In 1606, he wrote a petition to Strasbourg city council trying to protect his rights against reprints of his newsletters (see box below).



Relation:

Aller Fürnem-
men/ vnd gedenckwürdigen
Historien / so sich hin vnnd wider
in Hoch vnnd Nieder Teutschland / auch
in Franckreich/ Italien/ Schott vnd Engelland/
Hispanien / Hungern / Polen / Siebenbürgen/
Wallachey / Moldaw / Türckey / rc. Inn
diesem 1609. Jahr verlauffen
vnd zutragen möchte.

Alles auff das trewlichst wie
ich solche bekommen vnd zu wegen
bringen mag / in Truck ver-
fertigen will.

THE BIRTH CERTIFICATE OF THE NEWSPAPER

THIS 1606 petition made by Johann Carolus to Strasbourg city council was discovered in the Strasbourg Municipal Archives in the 1980s: ‘*Whereas I have hitherto been in receipt of the weekly news advice* [handwritten news reports] *and, in recompense for some of the expenses incurred yearly, have informed yourselves every week regarding an annual allowance; Since, however, the copying has been slow and has necessarily taken much time, and since, moreover, I have recently purchased at a high and costly price the former printing workshop of the late Thomas Jobin and placed and installed the same in my house at no little expense, albeit only for the sake of gaining time, and since for several weeks, and now for the twelfth occasion, I have set, printed and published the said advice in my printing workshop, likewise not without much effort, inasmuch as on each occasion I have had to remove the formes from the presses.*’

In 1605, Carolus published *Relation aller Fürnemmen und gedenckwürdigen Historien* (‘Collection of all distinguished and

commemorable news'), which is recognized as the world's first newspaper. The newspaper is made available by the printing press, from which the term applied generically to journalists and media – the *press* – takes its name. If we define a 'newspaper' by the functional criteria of publicity, seriality, periodicity and currency (that is, as a single current-affairs series regularly published at intervals short enough to keep abreast of incoming actual news), then this was the first newspaper. By the mid-17th century it is estimated that political newspapers, which enjoyed the widest popularity, reached up to 250,000 readers in the Holy Roman Empire, around a quarter of the literate population. Today, billions of people read daily newspapers thanks in the first instance to Johann Carolus and to the many people who came after him.

LOGARITHMS AND DECIMAL POINT

—— 1614 ——

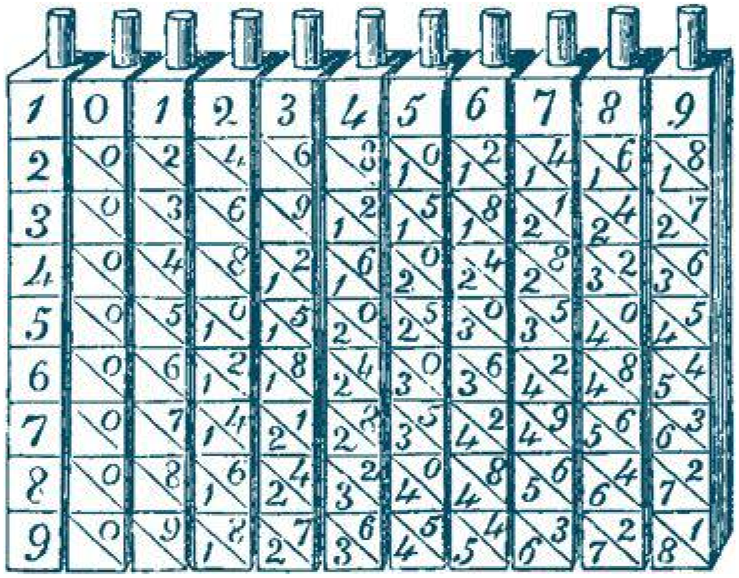
JOHN NAPIER (NEPER) 1550–1617, SCOTLAND

Without Napier's work on logarithms, it is difficult to imagine how contemporary and later scientists could have made their great advances. Napier also facilitated the development of the *slide rule*, the main calculator of large numbers for over 300 years. Some of us will remember the use of *log-tables* and slide rules at school, well before the invention of the pocket calculator. Napier's study of mathematics was only a hobby, and he wrote that he often found it hard to find the time for the necessary calculations, because he had been working on theology in which he was greatly interested. He is best known for his invention of logarithms but his other mathematical contributions include a mnemonic for formulae used in solving spherical triangles, two formulae known as *Napier's analogies* used in solving spherical triangles and an invention called *Napier's bones* or *Napier's Rods* used for mechanically multiplying, dividing and taking square roots and cube roots. Napier's small treatise on a simple way to perform multiplication, the *Rabdologiae*, was printed version of the abacus-like calculator that was known as *Napier's bones*. In an appendix he explained another method of multiplication and division using metal plates, which is the earliest known attempt at devising a mechanical means of calculation – the ancestor of our modern day calculator.

POINTS OF DIFFERENCE

THE SYMBOL used to separate the *integer* part of a decimal number from its *fractional* part is called the decimal point. In the United States, the decimal point is denoted with a period (3.1415), whereas a raised period is used in Britain (3.1415) and a decimal comma in used in Europe (3,1415). The number 3.1415 or 3.1415 is spoken in the USA and Britain as ‘*three point one four one five*’, while in continental Europe, 3,1415 would be spoken as ‘*three comma one four one five.*’

Napier’s interest in astronomy led to his interest in mathematics, as astronomical research required time-consuming calculations of very large numbers. To find a better and simpler way to perform large number calculations, Napier spent 20 years developing logarithms. A logarithm is a power to which a base (actually 10) must be raised to produce a given number. If n*x* = a, the logarithm of a, with n as the base, is *x*. His logarithm tables were a stroke of genius and were immediately used by astronomers and scientists. It is said that English mathematician Henry Briggs was so influenced by the tables that he travelled to Scotland just to meet Napier. This led to a cooperative improvement including the development of Base 10 (the numbering system in common use, in which each place to the left or right of the decimal represents a power of 10). Briggs began compiling a more practical table using Base 10, as Napier died soon after in 1617. Napier was also responsible for advancing the notion of the decimal fraction by introducing the use of the *decimal point*. His suggestion that a simple point could be used to separate whole number and fractional parts of a number soon became accepted practice throughout Britain. Instead of writing 3¾, people could write 3.75. Napier correctly forecast that the decimal point would revolutionize mathematics. The use of the decimal point, in one form or another, was being generally discussed in Napier’s time, and it is unlikely that any single person can be positively credited with the invention. However, Napier was one of the earliest to have adopted and promoted its use.



John Napier’s 1614 *Mirifici Logarithmorum Canonis Descriptio* contained 37 pages of explanatory matter and 90 pages of tables, which facilitated the development of astronomy, dynamics and physics. In its preface Napier wrote that he hoped that his logarithms would save calculators much time, and free them from the *slippery errors* of calculations. It was also a vital tool for navigators. To spend an hour working out trigonometric calculations would mean that the result would be an hour out of date, but Napier’s *logs* shortened the calculation to a few minutes. Two hundred years later, Laplace wrote that logarithms. ‘…*by shortening the labours, doubled the life of the astronomer*’. Logarithms were in common use for more than two centuries after Napier’s death, and were taught as a subject in college mathematics curricula until the late 1960s, when the scientific calculator replaced them for most calculations. In 1621, English mathematician William Oughtred (1574–1660) used ‘Napier’s bones’ and logarithms, when he invented the standard rectilinear *slide rule* and circular slide rule. A version of the slide rule was still being used in the 1970s by scientists at NASA to assist the development of space travel. Napier’s place in history is assured. The 1911 *Encyclopaedia Britannica* states: ‘…*Mirifici Logarithmorum Canonis descriptio…can be placed as second only to Newton’s Principia.*’

NAPIER’S ‘SECRET INVENTIONS’

NAPIER WROTE of several inventions with which ‘*to defend the country from Philip of Spain*’. One was a precursor of the tank, a round chariot that allowed its occupants to move speedily while firing through holes in its sides. He described a ship which could travel under water, a burning mirror which would consume enemy ships and an artillery piece which could destroy a whole field of soldiers. Napier also recommended using salt as a fertilizer among his many ideas for better farming.

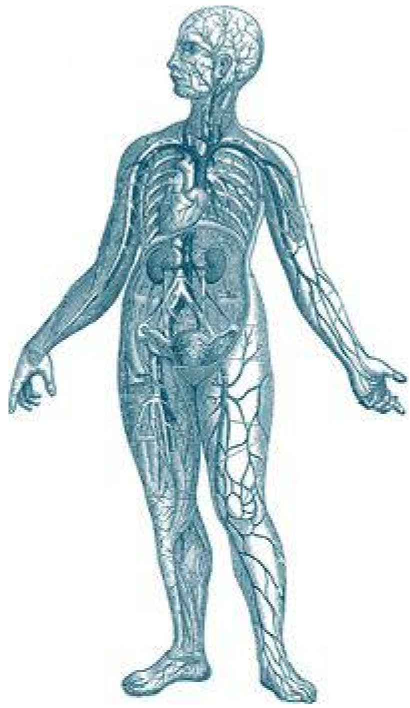
CIRCULATION OF BLOOD

—— 1628 ——

WILLIAM HARVEY 1578–1657, LONDON, ENGLAND

Harvey was the first man to describe accurately how blood is pumped around the body by the heart, a discovery that led to major advances in surgery and treatment. Harvey was educated at Cambridge University, then studied medicine at the university of Padua in Italy, at that time the foremost medical school in Europe. The great scientist, surgeon and anatomist Hieronymus Fabricius tutored him. Fabricius recognized that the veins in the human body had one-way valves, but was unsure as to their function. On his return from Italy Harvey married the daughter of Elizabeth I’s physician, and he became a fellow of the Royal College of Physicians in 1607. In 1618 he became physician to Elizabeth’s successor King James I and later to James’s son Charles I, being present at the inconclusive Civil War battle of Edgehill in 1642.

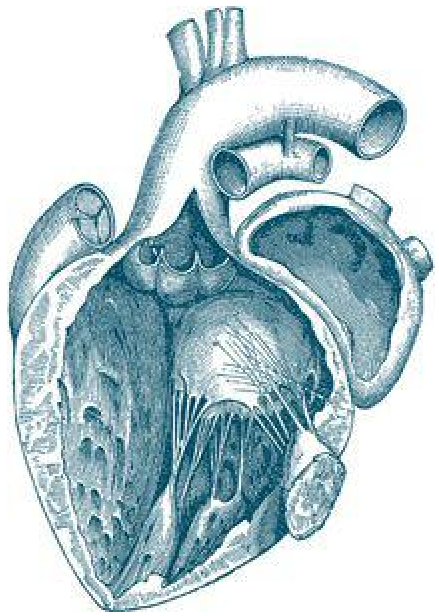
At the time scientists believed that the liver converted food into blood and the various parts of the body consumed the blood, but by 1615 Harvey was working on his theory that blood actually circulated around the body. In 1616 he discussed in his lectures at the College of Physicians this radical theory. In order to prove it, Harvey studied the motion of the heart and blood in live animals, and carried out dissections on the bodies of executed criminals. Harvey was able to disprove Galen’s second-century theory that the body made new blood as it used up the old. He saw that the heart acted as a pump which forced the blood around the body through arteries and that the blood was returned to the heart through the veins. Harvey discovered that the one-way valves described by Fabricius meant that blood could only flow in one direction.



In 1628 he published his theories in *An Anatomical Study of the Motion of the Heart and of the Blood in Animals,* but his research was received with great scepticism by contemporaries who distrusted new ideas, especially as Harvey's findings called into question the widespread practice of *blood letting*. This was widely carried out because it was believed that illness was sometimes caused by there being too much blood in the system. As a result, blood-letting continued to be a standard practice for many years. In 1651, Harvey wrote that animals did not spontaneously generate, and that life began from an egg. He theorized that the joining of a sperm and an egg was the beginning of life. Not until 200 years later were microscopes capable of seeing a mammalian egg.

THE FOUNDATION OF LIFE

'*THE HEART of animals is the foundation of their life, the sovereign of everything within them, the sun of their microcosm, that upon which all growth depends, from which all power proceeds*'. William Harvey, *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* ('An Anatomical Study of the Motion of the Heart and of the Blood in Animals'), 1628



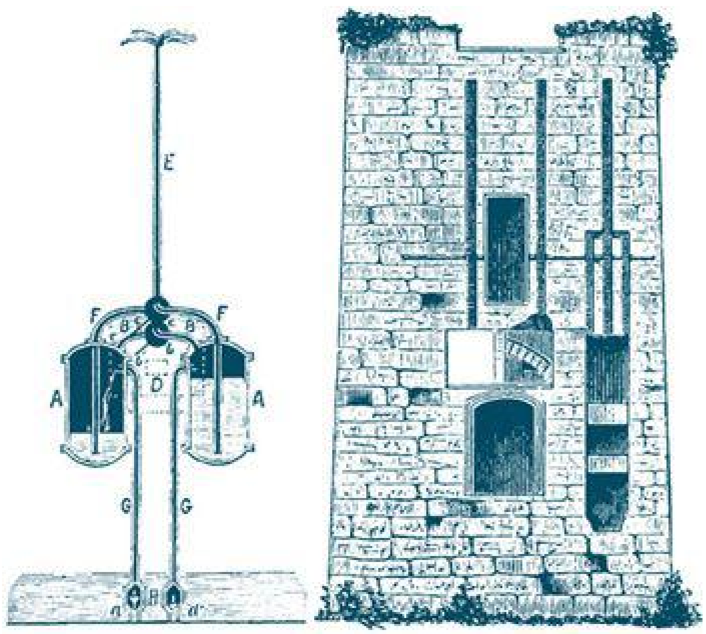
STEAM ENGINE

—— 1641 ——

LORD EDWARD SOMERSET, 2ND MARQUESS OF WORCESTER 1601–1667, RAGLAN, WALES

Formerly known as Lord Herbert of Raglan Castle, in 1655 Somerset wrote a book describing over 100 inventions, including the steam engine. Unfortunately, his huge fortune was lost in supporting the Royalists in the Civil War, but there is evidence that he had a steam pump in operation before war broke out in 1642. He was later too impoverished to resurrect his invention. The pump he describes used steam in two ways. First, steam was allowed into a sealed chamber which was then cooled. This created a vacuum, which sucked open a valve connecting to a pipe, with its end in the water which was to be pumped. Water rushed up the pipe into the empty chamber and, pressure then being equalized, the valve closed of its own accord. Then, more steam was admitted and the water in the chamber was forced upwards through another valve into the exit pipe, to a height of perhaps 40 feet (12 m). In the great ruins of Raglan Castle, despoiled in the Civil War, stands the six-sided Yellow Tower of Gwent, which in height and strength surpassed almost every other tower in Britain. This tower was joined to the castle by an arched bridge having an outer wall with six arched

turrets, adjoining a deep moat 30 feet (9 m) broad. Here Lord Herbert had artificial waterworks, which by means of steam he made spout up to the height of the castle. The position of these waterworks, as described by a contemporary, can even now be traced. In the stonework on the side of the wall facing the moat are grooves which mark the spot where steam was first used in England.



The Scottish writer Samuel Smiles tells us: '*One of his first cares, on the partial recovery of his property* [after the Civil War], *was to obtain a legal protection for his inventions; and in the year following the Restoration we find him taking out a patent for four of his schemes, – a watch or clock, guns or pistols, an engine to give security to a coach, and a boat to sail against wind and tide. In the session of Parliament, 1662–3, he obtained an Act securing to himself the profits of the watercommanding engine.*'

Regarding the boat invention, Somerset said it was '*applicable to any vessel or boat whatsoever, without being therefore made on purpose, and worketh these effects: it roweth, it draweth, it driveth, (if need be) to pass London Bridge against the stream at low-water, and a boat laying at anchor, the engine may be used for loading or unloading.*'

SOMERSET'S DEFENCE OF RAGLAN CASTLE

‘*At the commencement of the rebellion some country men, in the interest of the Parliament, came to search the castle for arms; it was not then garrisoned. Lord Herbert admitted them, and “brought them over the high bridge” – of which we have spoken – “that arched over the moat between the castle and the great tower, wherein Lord Herbert had newly contrived certain waterworks, which, when the several engines and wheels were to be set a-going, much quantity of water through the hollow conveyances of the aqueducts was to be let down from the top of the high tower.” These engines were set to work, and the rustics, who had never heard the noise and roar of steam engines, were so terrified that they ran away as fast as they possibly could, and only drew breath outside the castle, being told that the lions had got loose; for the earl had – as was the custom then a menagerie within his courts. The water could also be so managed as to wash away by its sudden rush any assailants in the courts.*’ Taken from description of Raglan Castle in Laura Valentine, *Picturesque England*, 1891

Worcester’s engine was granted a patent in 1663, with Somerset calling it his *water commanding* engine, as its function was to raise water. The steam pump could have been used for supplying water to canals, or for draining water from mines or marshes. A model of the engine was demonstrated at Vauxhall, London from 1663 until 1667, the year of Worcester’s death, and the device was illustrated in *History and progress of the steam engine* in 1830. Made from the barrel of a cannon, it was the prototype for what we know as the steam engine, and Somerset noted that a vessel of steam could raise 40 similar vessels of water 40 feet (12 m) in the air. When he died Somerset suggested that a model of what he called his *semi-omnipotent* engine should be buried with him, so proud was he of its invention.

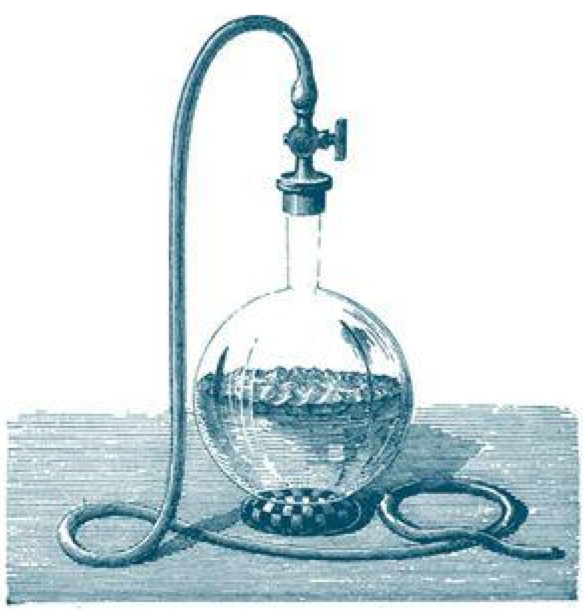
In 1663, separate accounts by Sorbière and Magalotti describe his steam engine working. Samuel Smiles, in his *Lives of Boulton and Watt* (1865), makes a firm case for this being the genesis of the modern steam engine (see Newcomen). Somerset never made a penny out of his machine, but the idea was again taken up more than half a century later by Thomas Savery, who probably read about it in Somerset’s 1655 book, and is also credited with being the inventor of the steam engine. The steam engine was the driving force of the Industrial Revolution across the world.

BOYLE’S LAW, PROOF OF VACUUM

—— 1662 ——

ROBERT BOYLE 1627–1691, IRELAND AND ENGLAND

This ‘founder of chemistry’ advanced the understanding of the behaviour of atoms and can be regarded as the first modern chemist. Boyle was the seventh son of the earl of Cork, who was then the richest man in the United Kingdom. This enabled Boyle to enjoy extensive European travel, from which he returned in 1644 extremely interested in science. He thereupon built his own laboratory. In 1655 or 1666, he engaged Robert Hooke as an assistant and together they devised the most famous piece of experimental equipment associated with Boyle, the *vacuum chamber* or *air-pump*. Boyle made important contributions to physics and chemistry and is best known for Boyle’s Law (sometimes called Mariotte’s Law) describing an ideal gas: ‘*For a fixed amount of an ideal gas kept at a fixed temperature, P [pressure] and V [volume] are inversely proportional (while one doubles, the other halves).*’ Boyle’s Law appears in an appendix written in 1662 to his work *New Experiments Physio-Mechanicall, Touching the Spring of the Air and its Effects* (1660). The book was the result of three years of experimenting with an air pump designed by Hooke. Boyle discovered that sound did not travel in a vacuum, proved that flame needed the presence of oxygen (as did life), and investigated the elastic properties of air.



FORETELLING THE FUTURE

IN 24 handwritten notes, Robert Boyle set out the most pressing problems for scientists to solve. It is remarkable how many of them have become reality over the intervening centuries. His wish list for scientists begins, simply, with '*The Prolongation of Life*', as life expectancy at birth at the time was less than 40 years. Boyle also wished to develop a means to recover youth, or at least some of its outward signs. Boyle speculated that false teeth and hair colouring would one day be possible. He wished to perfect '*the Art of Flying*'. This was nearly a century after Leonardo da Vinci had sketched out designs for *ornithopters*, but it would be another century before the Montgolfier brothers achieved the first hot air balloon flight. The Wright Brothers pioneered powered flight from 1903, over 200 years after Boyle's death.

Boyle hoped for a way to '*Cure Wounds at a Distance, or at least by Transplantation*', which has become a reality with the advent of organ transplants and robotic surgical tools that can be operated from thousands of miles away. The first successful kidney transplant was performed in 1954 in Boston. Boyle also hoped that scientists would find ways for people to work underwater and develop '*A Ship to sail with All Winds, and a Ship not to be Sunk.*' Since then we have developed engine-powered boats, and modern passenger ships are almost impossible to sink. The most radical items on Boyle's list touch on human physiology and the brain. He suggests that scientists might devise ways to live on a minimal amount of sleep by studying the effects of tea and also examining lunatics who appeared to need very little sleep. His note is entitled: '*Freedom from Necessity of much Sleeping exemplify'd by the Operation of Tea and what happens in Mad Men.*' Caffeine is present in tea, but the first coffee house in Britain was not set up until 1652.

He looked forward to ‘*Potent Druggs to alter or Exalt Imagination, Waking, Memory, and other functions, and appease Pain, procure innocent Sleep, harmless Dreams, etc.*’ as he had great faith in the power of pharmaceuticals. LSD, aspirin and sleeping tablets achieve these effects. His note on ‘*Attaining Gigantick Dimensions*’ has been achieved with respect to vegetables. ‘*The Transmutation of Species in Minerals, Animals and Vegetables*’ could refer to transplants and genetic engineering. ‘*The Acceleration of Things out of Seed*’ which points the way to today’s advances in agriculture and genetic crops. He desired ‘*the practicable and certain Way of finding Longitudes*’ which anticipated Harrison’s chronometers and the satellite technology developed in the 1970s for GPS navigation. Along with underwater exploration, Boyle wanted ‘*The making of Armour extremely Light and extremely Hard*’ – Kevlar invented in the 1960s is extremely light and stronger than steel.

Boyle’s Law states that if the volume of a gas is decreased, the pressure increases proportionally. Because density depends on volume, the smaller the volume, the higher the density. So when pressure is applied, volume is reduced i.e. density is increased. Thus, at higher altitudes, as the atmospheric pressure is low, the air is less dense and less oxygen is available for breathing. Understanding that his results could be explained if all gases were made of tiny particles, Boyle tried to construct a universal *corpuscular theory* of chemistry. He had expressed the proof the gases are compressible. When a given mass of gas is compressed, the same number of molecules occupy a smaller space (the gas becomes denser). His *corpuscular or mechanical hypothesis* was the most developed understanding of physical atomism up to this time. It was not until 1800, with John Dalton’s rediscovery of the Greeks’ *atomist* theories, that Boyle’s *particle theory* would gain acceptance.

Boyle defined the modern idea of an *element* in *The Sceptical Chymist* of 1661, as well as introducing the litmus test to tell acids from bases, and he established many other standard chemical tests. At this time even the idea of an experiment was still controversial. The established method of ‘discovering’ something was to argue it out, using the established logical rules that Aristotle and others had worked out 2000 years earlier. Boyle was more interested in observing nature and drawing his conclusions from what actually happened. He was the first prominent scientist to perform

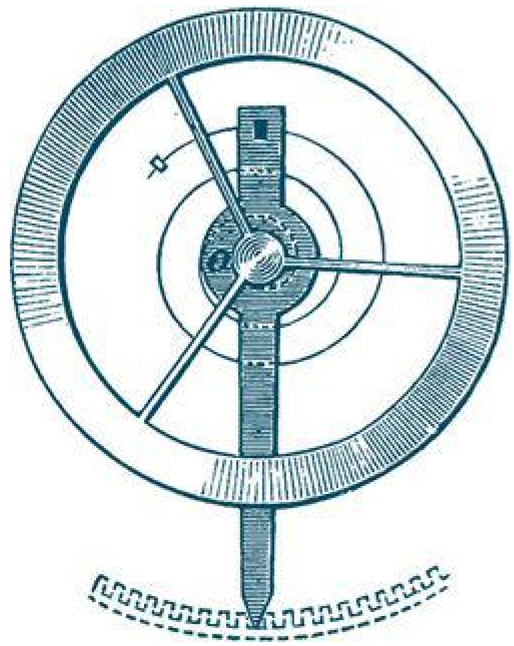
controlled experiments and also to publish his work with details concerning procedure, apparatus and observations. He also worked on the calcination of metals, the properties of acids and alkalis, specific gravity, crystallography and refraction and was the first scientist to prepare phosphorus. He began to publish in 1659 and continued to do so for the rest of his life on subjects as diverse as philosophy, medicine, hydrostatics and religion. In 1660, together with 11 other scientists, Boyle formed the Royal Society in London which met to witness experiments and discuss what we would now call scientific topics.

WATCH BALANCE WHEEL

—— 1662 ——

ROBERT HOOKE 1635–1703, ENGLAND

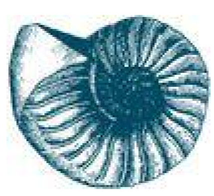
Hooke's spring balance wheel made possible the portable timepiece and allowed far greater accuracy in timekeeping. He was the first to see and describe a *cell* by using a microscope. Hooke was a polymath and has been called '*England's Leonardo*' but is not as well-known as he deserves, possibly because of his disputes with Newton. Having worked closely with Robert Boyle, Hooke was at one time simultaneously a member of the council of the Royal Society, its curator of experiments, Gresham Professor of Geometry, an astronomer, an architect and Surveyor to the City of London after the Great Fire of London. Following the fire, Hooke carried out more than half the surveys needed, and was also commissioned to design replacement buildings. He invented the iris diaphragm, the spring control of the balance wheel in watches, the anchor escapement of clocks, an odometer, an *otocousticon* as an aid to hearing, a reflecting quadrant, the compound microscope, a wheel barometer and the universal (Hooke's) joint that is found in all motor vehicles. He made important contributions to the design of astronomical instruments, being the first to insist on the importance of resolving power in lenses, and the advantage of using hair lines in place of silk or metal wire. Hooke built the first reflecting Gregorian telescope in 1673, observed the rotation of Mars, and noted one of the earliest examples of a double star.



In 1657 Hooke began work to improve pendulum mechanisms, going on to study both gravitation and the mechanics of timekeeping. Hooke recorded that he conceived of a way to determine longitude, and attempted to patent it. In 1660, Hooke discovered the *Law of Elasticity*, describing the linear variation of tension with extension in an elastic spring, but he did not publish the proof for 18 years. Hooke's work on elasticity culminated, for practical purposes, in his development of the balance spring, which for the first time enabled a portable timepiece, a watch, to keep time with reasonable accuracy. In the process, Hooke demonstrated a pocket-watch of his own devising, fitted with a coil spring attached to the arbour of the balance. Hooke stopped work in this area, as he could not attract investors, but he developed the balance spring (*hairspring*) 15 years before Huygens published details of his invention in 1675. A note dated 23 June 1670 in the *Hooke Folio* described a later demonstration of his balance-controlled watch before the Royal Society. Hooke also invented the anchor escapement for pendulum clocks, which allowed the clock's wheels to advance a fixed amount for each pendulum swing, moving the hands regularly forward. Until the deadbeat mechanism of 1715, this was a great advance in timekeeping accuracy Hooke suggested a wave theory of light in his *Micrographia* (1665), comparing the spreading of light vibrations to that of waves in water. He suggested in 1672 that the vibrations in light might run perpendicular to the direction of propagation. He investigated the

colours of membranes and of thin plates of mica, and established the variation of the light pattern with the thickness of the plates. *Micrographia* contained a series of observations made with the aid of magnifying lenses, some relating to very small things, some to astronomical bodies. Hooke invented microscopes and applied his technical abilities to devise ways of controlling their height and angle, as well as mechanisms of illumination. Variations in light allowed Hooke to see new detail in his samples, and he used multiple sources of illumination before producing any single drawing. Hooke's technical efforts created magnifications of 50 times, enabling insight to a world not previously known.

King Charles had requested Hooke to carry out insect studies, but Hooke went beyond his royal commission and looked at everything including fabric, leaves, mica, glass, flint and even frozen urine. Hooke let a louse suck blood from his hand to see how the blood travelled through its innards, and stung himself with nettles to see where and how the poison was pumped into his hands. Hooke viewed a thin slice of cork and discovered empty spaces contained by walls which he termed pores, or *cells*. Hooke gained credit for discovering the building blocks of all life. Less well-known is his invention of the term 'cell' in a biological context as a result of his studies of cork, the term being suggested by the resemblance of plant cells to monks' cells. Hooke's experiments also led him to conclude that combustion involves a substance that is mixed with air. If he had continued these experiments, some believe that he would have discovered oxygen. One of the observations in *Micrographia* was of fossil wood, and he concluded that fossilized objects like petrified wood and fossil shells, such as ammonites, were the remains of living things that had been soaked in petrifying water laden with minerals. Hooke thus believed that such fossils provided reliable clues to the past history of life on Earth.



THE FIRST DESCRIPTION OF A LIVING CELL

HOOKE'S best-selling *Micrographia* (1665) was a detailed record of all his microscopic findings, and it included the famous drawing of a flea, which he described as '*adorn'd with a curiously polish'd suite of sable Armour, neatly jointed.*' However, a contemporary satirist called Hooke '*a Sot, that has spent £2000 in Microscopes, to find out the nature of Eels in Vinegar, Mites in Cheese, and the Blue of Plums which he has subtly found out to be living creatures.*' The diarist Samuel Pepys, however, stayed up until 2a.m. one night reading the book, and praised it as '*the most ingenious book that I ever read in my life*'. Hooke wrote of his discovery of 'cells' in slices of cork: '*I could exceedingly plainly perceive it to be all perforated and porous, much like a Honey-comb, but that the pores of it were not regular…these pores, or cells,…were indeed the first microscopical pores I ever saw, and perhaps, that were ever seen, for I had not met with any Writer or Person, that had made any mention of them before this…*'

In his *Attempt to Prove the Motion of the Earth* (1674), Hooke offered a theory of planetary motion based on the correct principle of inertia and a balance between an outward centrifugal force and an inward gravitational attraction to the Sun. In 1679, in a letter to Isaac Newton, he finally suggested that this attraction would vary inversely to the square of the distance from the Sun. Hooke's theory was qualitatively correct, but he did not have the mathematical ability to give it an exact, quantitative expression. Hooke's interests in gravity had occupied his researches for over 20 years. In 1675, Newton's *Discourse on Colour* was objected to by Hooke on the grounds that '*the main of it was contained in Micrographia*'. In 1676, he published the principles of spiral springs in *A Description of Helioscopes*.

ENGLAND'S LEONARDO

ROBERT HOOKE's memorial tablet in the Crypt of St Paul's Cathedral is positioned next to that of his friend and colleague Sir Christopher Wren. It calls Hooke '*One of the most ingenious men who ever lived*'. The Monument to the Great Fire of London of 1666 was jointly the work of Sir Christopher Wren and Robert Hooke. At 206 feet (62.8 m) high, it is the tallest isolated stone column in the world. The Hooke Memorial inscription at the Monument describes Hooke as '*natural philosopher and England's*

Leonardo'. Dr Allan Chapman, in *Robert Hooke (1635–1703) and the art of experiment in Restoration England* (Proceedings of the Royal Institution of Great Britain, 1996) tells us: '*Robert Hooke was a figure of extraordinary and diverse creativity. With his grasp of ancient languages, the quality of his draughtsmanship as shown in the plates of* Micrographia, *and his success as an architect, he clearly possessed high artistic talents. And his craft skills enabled him to build an airpump where the country's leading pumping engineer had failed. But most of all, he was the man who showed that the "experimental philosophy" actually worked and could be used to extend the bounds of natural knowledge. He was Europe's last Renaissance man.*'

Hooke is best known today for Hooke's Law: '*The extension of a spring is proportional to the weight hanging from it*'. This work sprang from Hooke's interest in flight and the 'spring' or elasticity of air. His 1660 discovery was not published until *De Potentia Restitutiva* in 1678, and it gives us virtually the present notions of elasticity and the kinetic theory of gases. His interest in gases and their properties also found expression in his work on respiration. In one experiment he sat inside a sealed bell jar, from which the air was gradually pumped. His ears and nose were damaged as his body tried to adjust to the change in pressure. In 1666, Hooke expounded that gravitation was an attractive force. Hooke's 1670 Gresham lecture later explained that gravitation applied to '*all celestiall bodys*' and added the principles that the gravitating power decreases with distance, and that in the absence of any such power bodies move in straight lines. In 1679, Hooke wrote to Newton stating that gravitation had inverse square dependence, and was furious when Newton received the credit for this discovery. In 1678, *Cometa* was published, dealing with the 'Great Comet' of 1677 and including a statement of the *Law of Inverse Squares*.

GEOLOGICAL STRATA

—– 1669 —–

NICOLAS STENO 1638–1686, DENMARK AND TUSCANY

Steno (Nils or Niels Stensen or Steensen) studied medicine across Europe, and when dissecting a sheep's head, he was the first person to

discover the excretory duct of the parotid gland, which supplies saliva to the mouth. It is known today as Stensen's duct. In later years, he uncovered the nature of muscle contractions, and the muscular nature of the human heart (thought by some at that time to generate heat, not pump blood). Like his studies of the heart, Steno's careful dissections of human brains disproved some of the speculations of many scientists, including Descartes. Steno rejected the Aristotelian elements of earth, water, air and fire, which were each supposed to have distinct shapes: icosahedron for water, tetrahedron for fire, cube for earth and octahedron for air. By examining grains of sand under a microscope, Steno discovered in 1659 that they had a variety of shapes: '*pyramidal*, *pentahedral*, *cubic*, *heptahedra*, *trapezia…*' Steno became physician to the Grand Duke Ferdinand II in Florence, and in 1666 he dissected the head of a large shark at the duke's request. He concluded that the *glossopetrae* (*tongue stones*, or fossil teeth) found in rocks were identical to shark's teeth. It was commonly thought that they were serpent's tongues turned to stone by St Paul. Steno then intensively researched geology across Tuscany, and published *De Solido Intra Solidium Naturaliter Contento Dissertationis Prodromus* ('Forerunner of a Dissertation on a Solid Naturally Contained within a Solid') in 1669. This was a firm statement of the organic origin of fossils, and a description of how fossils became enclosed in layers of rock. Steno also enunciated the fundamental principles of stratigraphy. Based on the *Dissertationis Prodromus*, Steno is often considered 'the father of geology'. The work was supposed to be an introduction to a much more detailed work, but the larger book never appeared as Steno turned his attention to religion.

Steno reasoned that each stratum is deposited from fluid upon a solid subjacent surface, and that hard (solid) fossils may be incorporated into soft (loose) sediment at this stage. Each stratum is laterally continuous and approximately horizontal. Superposition (stacking) of strata takes place according to age, and any deviation is due to later alteration as might be caused by an earthquake, volcano, etc. Fossils are anatomically identical with parts of living organisms, particularly teeth, bones, and shells. Fossilization into crystalline material takes place over long passage of time, thus many fossils must be as old as the general deluge (the Biblical Flood). Steno interpreted all rocks in terms of deposition of sediment from fluid. He apparently knew nothing of granite or lava, which are not present in Tuscany. However, his conclusions were not generally accepted until the following century. Catholic censors had to approve all scientific publications in Steno's time. The first censor, Vincenzo Viviani, was sympathetic and approved; however, the second censor delayed for four months before giving approval. During this period, Steno lost interest, probably because of personal religious conflicts and he left Florence to take up a new post as royal anatomist in Copenhagen. The publication in 1669 was ultimately arranged entirely by his first censor, Viviani. Steno's geological career spanned only three years, as he became a priest in 1675 and completely gave up science for the remainder of his life. Steno was beatified by Pope John Paul II in 1987, the first step to being declared a saint by the Roman Catholic Church.

THE BEGINNING OF THE WORLD

STENO LIVED at a time when people believed in all sorts of myths. It was thought that fossils grew inside rocks, witches were everywhere, crystals and unicorn horns cured disease, lowly animals emerged spontaneously from decaying matter and the motions of stars and planets decided fortunes

and personalities. Many people still believe the latter statement. It was a time of intense religious strife, but all Catholics and Protestants agreed on the date of 4004 BCE for the creation of the world, as determined by the Irish Anglican archbishop James Ussher (1581–1656). Steno was deeply religious and never publicly disputed this estimate of Earth's age. Some see Steno's embrace of religion as an implicit rejection of his geological studies, but he did not feel this way, writing: '*One sins against the majesty of God by being unwilling to look into nature's own works and contenting oneself with reading others; in this way one forms and creates for oneself various fanciful notions and thus not only does one not enjoy the pleasure of looking into God's wonders but also wastes time that should be spent on necessities and to the benefit of one's neighbour and states many things which are unworthy of God.*'

BACTERIA

—— 1676 ——

ANTONIE VAN LEEUWENHOEK 1632–1723, HOLLAND

Antonie van Leeuwenhoek was an apprentice in a Dutch dry goods store, and he used magnifying glasses to count the threads in cloth. Drapers regularly used magnifying glasses to inspect the quality of cloth, and van Leeuwenhoek taught himself new methods for hand grinding and polishing tiny lenses of great curvature which gave magnifications up to 270x diameter, the finest known at that time. Van Leeuwenhoek ground more than 500 optical lenses, and made at least 250 of what are considered to be the first practical microscopes, of which only nine survive. Van Leeuwenhoek was the first scientist to see and describe bacteria, the structure of yeast cells, the incredible life forms in a drop of water and the circulation of blood corpuscles in capillaries. For more than 50 years he pioneered an extraordinary variety of discoveries, reporting his findings in more than 100 letters sent to the Royal Society of England and the French Academy.

In 1673, he reported on his first observations – bee mouthparts and stings, a human louse and a fungus – to the Royal Society. In 1674, van Leeuwenhoek discovered *protists*, single-celled organisms in water, the first micro-organisms observed by man. His 1676 letter announcing this

discovery caused controversy and some doubt at the Royal Society, as the existence of single-celled organisms was unknown. However, Robert Hooke later repeated his experiment and was able to confirm the discoveries in 1680. Van Leeuwenhoek was then elected a member of the society in 1680, and reported his findings in correspondence to the Royal Society for the rest of his life.

ANIMALCULES, BACTERIUM AND BACILLUS

VAN LEEUWENHOEK called the bacteria which he first observed *animalcules* in his letters to the Royal Society. The name *bacterium* was not introduced until Christian Gottfried Ehrenberg's work in 1828. *Bacterium* is a genus which contains non-spore-forming rod-shaped bacteria. *Bacillus* is a genus of spore-forming rod-shaped bacteria as defined by Ehrenberg in 1835.

As well as being the 'father of microbiology', van Leeuwenhoek laid the foundations of plant anatomy and became an expert on animal reproduction. He discovered blood cells and microscopic nematodes, and studied the structure of wood and crystals. By 1677 he had discovered spermatozoa, and described the spermatozoa of molluscs, fish, amphibians, birds and mammals, coming to the conclusion that fertilization occurred when the spermatozoa penetrated the egg. In 1682 he described the banded pattern of muscle fibres, and also wrote about blood flow in capillaries. Van Leeuwenhoek's discovery that smaller organisms procreate in a similar way to larger organisms challenged contemporary beliefs that such organisms generated spontaneously. He died of a rare disease that causes uncontrolled

spasms of the midriff. The condition is now known as van Leeuwenhoek's disease or respiratory myoclonus.

POSTAGE STAMP

—— 1680 ——

WILLIAM DOCKWRA *C.*1635–1716 AND ROBERT MURRAY (N.A.), ENGLAND

The adhesive postage stamp revolutionized communications within and between countries across the world. Before the introduction of postage stamps, delivered mail was paid for by the recipient. This led to a variety of problems, such as when the receiver was unable or unwilling to pay for the delivery service. It also allowed the delivery of pieces of mail just to annoy the receiver, and forced them to pay for it at the same time. (Imagine having to pay for today's 'spam' emails, unwanted texts or junk post.) Mail was also often lost or severely delayed. The answer came in 1840, in the form of the postage stamps that were recommended as part of Sir Rowland Hill's postal reforms. Instead of requiring the receiver to pay the postage for mail, the burden was shifted onto the sender. Letter writers now had to buy a *Penny Black* stamp and affix it to the package using glue (stamps were not selfadhesive), and drop it off at the post office.

THE MOST VALUABLE OBJECT CREATED BY MAN, RELATIVE TO ITS WEIGHT AND SIZE

THE WORLD'S most expensive stamp was printed in Sweden in 1855 and was the result of a printing error. Instead of printing the three-skilling stamp on green stock, it was printed on yellow/ orange stock paper. Only one copy of the *Treskilling Yellow* postage stamp is known to exist. It first achieved a million-dollar price tag when it was sold in 1990. Six years later, it was sold for 2.5 million Swiss francs, around 2.3 million US dollars. In 2010, the stamp made headlines again with a record-breaking sale. While the exact figure is unknown, the auctioneer revealed that it at least maintained the $2.3 million price achieved in 1996.

The famous Penny Black is not an exceptionally rare stamp, each one being currently worth between $240 and $3000 depending on its condition. About 68 million Penny Black stamps were issued during 1840–1 and it is estimated that about 1.5 million Penny Blacks survive today. However, a

rare specimen of this stamp with a red Maltese cross cancellation sold at auction for more than $2.4 million.

The US Franklin Z-Grill of 1867–8 is undoubtedly the rarest of all postage stamps in the United States, with only two known stamps remaining. In 1988 a ‘Z-Grill’ one cent stamp of 1868 sold at auction for about $1.5 million.

However, the first postage stamps predated the Penny Black by almost two centuries. The London City Post, established by Robert Murray and shortly after taken over by William Dockwra, used handstamps in about 1680. However, Robert Murray was arrested in May 1680, along with another associate of the London City Post, George Cowdron, for distributing by means of the *Penny Post* what was considered to be seditious material criticizing the Duke of York (later James II). This left Dockwra to manage the Penny Post on his own. Its triangular handstamp bore the text ‘*Penny (Post) Paid*’, and in the centre a sign denoted the post office where the letter was posted. Though this ‘stamp’ was applied to the letter instead of a separate envelope, it is considered by many historians to be the world’s first postage stamp. Dockwra opened post offices in all London districts. Letters were accepted at the seven borough post offices, at the main office in Lyne Street and at 400 to 500 mail collection stations. There were hourly collections, with a maximum of ten deliveries daily for London, and a minimum of six for suburbs such as Islington and Hackney. Dockwra’s Penny Post delivered letters and packets weighing up to one pound (454 g) and delivery was guaranteed within four hours, each letter being marked with a heart-shaped time stamp, indicating the time that an item was dropped off for delivery. Because the new postal service was affordable to the general public with its inexpensive flat rate of one penny, it became an almost instant success and was the predecessor of the postal systems that later emerged. Although the cost of postage was very cheap,

the London City Post showed such a profit that the state took it over in 1698 and Dockwra was dismissed in 1700.

Later, Rowland Hill's 1840 ideas for postage stamps, and charging for postage based upon weight, were a runaway success and they were adopted in many countries throughout the world. With the new policy of charging by weight, it became the norm to use envelopes for mailing documents. Hill's brother, Edwin Hill, invented a prototype envelope-making machine that folded paper into envelopes to match the pace of the growing demand for postage stamps. The first perforated stamps were issued in 1854. Following the introduction of the postage stamp in the UK, the number of letters dispatched increased dramatically as the use of the stamp rapidly accelerated. Before 1839 the number of letters sent in the UK was around 76 million a year. By 1850 this had increased to 350 million and continued to grow rapidly thereafter.

THE ROLE OF THE POSTBOX

THE POSTBOX, sometimes known in the USA and Canada as a collection box, mailbox or drop box, was necessary for the take-up of stamped letters. In the British Isles the first pillar postboxes were erected in Jersey in 1852. Roadside wall boxes first appeared in 1857 as a cheaper alternative to pillar boxes, especially in rural districts. In 1853 the first pillar box in Britain was installed in Carlisle. Green was adopted as the standard colour for the early Victorian postboxes. Between 1866 and 1879 the hexagonal 'Penfold'

postbox became the standard design for pillar boxes, and it was during this period that red was first adopted as the standard colour. The US Post Office began installing public mail collection boxes outside post offices and on street corners in large cities in the 1850s. Collection boxes were initially mounted on lamp-posts.

Postboxes quickly sprang up in response to the popularity of stamps. The post office received more money since people were paying up front for each letter, which allowed it to deliver mail more efficiently and on time. Soon other countries followed suit. Switzerland issued its own Zurich stamps in 1843, but based the charge upon delivery distance. In 1845 some US postmasters issued their own stamps, but it was not until 1847 that the first official US stamps were created, 5- and 10-cent issues depicting Benjamin Franklin and George Washington. The first adhesive postage stamp, the famous Penny Black and then the Twopenny Blue issued two days later, had tuly started a revolution in postal services across the world.

ANATOMY OF PLANTS

—— 1672–1682 ——

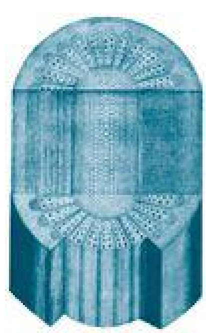
NEHEMIAH GREW 1641–1712, ENGLAND

In parallel with Marcello Malpighi (1628–94) this 'father of plant physiology' created the science of plant anatomy. A medical doctor, Grew began observations concerned with the anatomy of plants in 1664. In 670 his essay, *Anatomy of Vegetables Begun*, was communicated to the Royal Society by Bishop John Wilkins. On Wilkins's recommendation, Grew was elected a fellow in 1671 and became the secretary of the FRS in 1677, following in Robert Hooke's footsteps. In 1672, when the essay was published, Grew settled in London, and soon acquired an extensive practice as a physician. In 1673 he published his *Idea of a Phytological History*. In 1682 his great work on the *Anatomy of Plants* appeared, which was largely a collection of previous publications. It was divided into four books: *Anatomy of Vegetables Begun, Anatomy of Roots, Anatomy of Trunks* and *Anatomy of Leaves, Flowers, Fruits and Seeds*. For the first time Grew revealed the inner structure and function of plants in all their complexity, and paved the way for the science of plant anatomy. Grew described nearly

all the key differences of morphology of stem and root, and showed that the flowers of the Aster family are made of multiple units. He correctly hypothesized that stamens are male organs, and that pollen is fertilizing 'seed', being the first since Theophrastus to argue that plants have sexual properties. The German Rudolf Jakob Camerarius (1665–1721) is usually credited with this finding, but his work was not published until 1694.

PLANT SEX

ALTHOUGH Theophrastus, Camerarius and Grew have all been credited with discovering sexual reproduction in plants, in fact the Babylonians in around 2000 BCE knew that plants could either be male and bearers of fertilizing pollen, or female and bearers of fruit. Seals show Babylonians artificially fertilizing plants, and *c*.1800 BCE they were trading in male date palm flowers for this purpose.



Like Hooke, Grew used the microscope for his investigations and, along with Malpighi, he is remembered for establishing the observational basis for botany. *Anatomy of Plants* also contains the first known microscopic description of pollen, leading to the discovery that although all pollen is roughly globular, its size and shape varies between species. However, pollen grains within a species are all alike. Although Grew continued to publish throughout his life, especially on the chemical properties of various substances, all his works except for the *Anatomy* have fallen into obscurity. It was not certain, before Grew's work, that plants had an internal structure in which distinct parts or organs played important roles.

It had been thought that the external shape of a plant was a clue or *signature* to its use, but whether there was anything resembling organs in plants was contested. Grew's detailed observations established without a doubt that plants could be analyzed in terms of their functional and morphological units, reinvigorating a tradition that went back to Theophrastus. With Grew, we see the beginning of modern comparative anatomy. He was guided by the idea that there may be similarities of function between animals and plants and this led him to look for equivalent organs in each. He thus believed in the circulation of sap, being analogous with William Harvey's discovery of the circulation of blood in animals, and he correctly postulated a form of respiration in plants.

'…A PLANT, LIKE AN ANIMAL, HATH ORGANICAL PARTS…'

IN MANY ways a 1675 review best sums up the significance of Grew's scientific work, since much of his importance remains unappreciated today: '*In general, it is noted by our Author, that it will here appear, that there are those things which are little less wonderful within a Plant than within an Animal; that a Plant, like an Animal hath Organical parts, some whereof may be called its Bowels; that every Plant hath Bowels of divers kinds, containing divers liquors; that even a Plant lives partly upon Air, for the reception whereof it hath peculiar Organs. Again, that all the said Organs, Bowels, or other parts are as artificially made, and as punctually for place and number composed together as all the Mathematical Lines of a flower or Face; that the Staple of the Stuff is so exquisitely fine, that no Silkworm is able to draw so small a thread; that by all these means the ascent of the Sap, the Distribution of the Air, the Confection of several sorts of Liquors,*

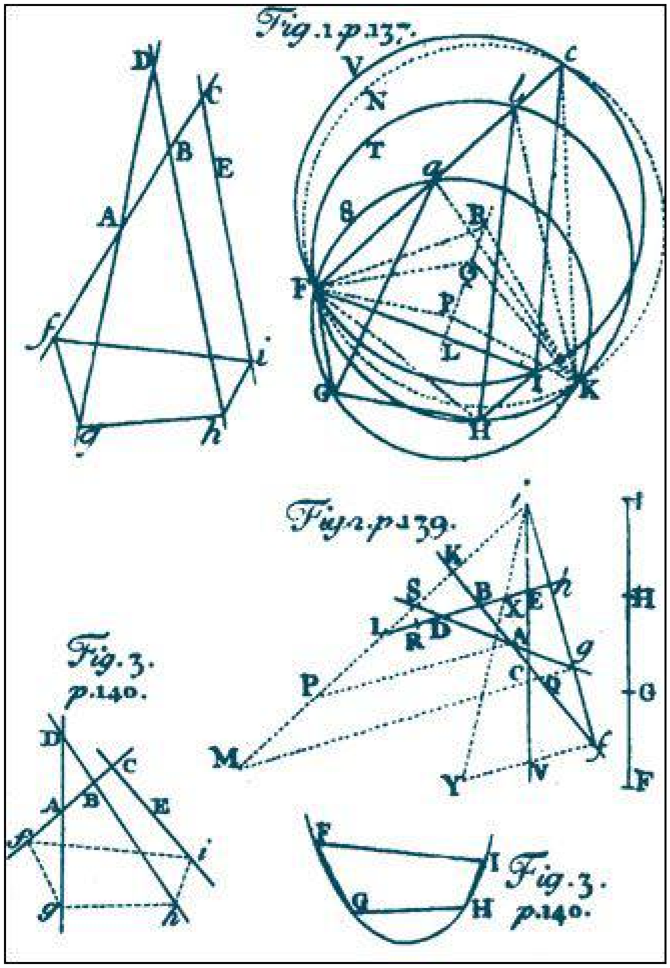
as Lymphus, Milks, Oils, Balsams, with other acts of Vegetation, are all contrived and brought about in a Mechanical way.' Philosophical Transactions, 1675

GRAVITY AND LAWS OF MOTION

—— 1687 ——

ISAAC NEWTON 1643–1727, ENGLAND

With the discovery of the Law of Gravity, Newton founded the sciences of classical mechanics and modern physics. However, how does one encompass Newton's contribution to human learning in a few words? He is acknowledged by many to be the most important scientist in history. Newton has been regarded for almost 300 years as the founding father of modern physical science, his achievements in experimental investigation being as innovative as those in mathematical research. In 1661, Newton entered Cambridge University where he became interested in mathematics, optics, physics and astronomy. It was Newton's reflecting telescope, which he made in 1668, that finally brought him to the attention of the scientific community. In 1665 or 1666 Newton famously watched an apple fall in his orchard. He hypothesized that the same force governed the motion of the Moon and of the apple. He calculated the force needed to hold the Moon in its orbit, as compared with the force pulling an object to the ground. He also calculated the centripetal force needed to hold a stone in a sling, and the relation between the length of a pendulum and the time of its swing.



This early work led to a study of astronomy and the problems of planetary motion. His correspondence with Robert Hooke (1679–80) redirected Newton to the problem of the path of a body, subjected to a centrally directed force which varies as the inverse square of the distance. Newton determined it to be an ellipse, and informed the astronomer Edmond Halley in 1684. Halley’s interest led Newton to demonstrate the relationship again, to compose a brief tract on mechanics, and finally to write his *Principia*, then known as *Philosophiae Naturalis Principia Mathematica* (‘Mathematical Principles of Natural Philosophy’). In 1687 this great work demonstrated how a universal force, gravity, applied to all objects in all parts of the universe. However, Hooke deserves much credit for Newton’s work.

Book I of the *Principia* stated the foundations of the science of mechanics, developing the mathematics of orbital motion around centres of force. Newton identified gravitation as the fundamental force controlling

the motions of all celestial bodies. Book II inaugurated the theory of fluids, in which Newton solved problems of moving fluids, and of motion through fluids. From the density of air he calculated the speed of sound waves. Book III demonstrated the law of gravitation at work in the universe, and in relation to the revolutions of the six known planets, including the Earth, and their satellites. Comets were shown to obey the same law, and in later editions Newton added conjectures on the possibility of their return repeatedly over time. He calculated the relative masses of heavenly bodies from their gravitational forces, and the oblateness of Earth and Jupiter. He explained and computed tidal ebb and flow, and the precession of the equinoxes, from the forces exerted by the Sun and Moon. Newton's work in mechanics was accepted at once in Britain, and more universally after half a century had elapsed. Since then it has been ranked among humanity's greatest achievements in abstract thought.

NEWTON'S APPLE

WILLIAM STUKELEY, one of Newton's first biographers, recorded in his *Memoirs of Sir Isaac Newton's Life* a conversation with Newton in 1726, in which Newton recalled: '…*when formerly, the notion of gravitation came into his mind. It was occasioned by the fall of an apple, as he sat in contemplative mood. Why should that apple always descend perpendicularly to the ground, thought he to himself. Why should it not go sideways or upwards, but constantly to the Earth's centre? Assuredly the reason is, that the Earth draws it. There must be a drawing power in matter. And the sum of the drawing power in the matter of the Earth must be in the Earth's centre, not in any side of the Earth. Therefore does this apple fall perpendicularly or towards the centre? If matter thus draws matter; it must be proportion of its quantity. Therefore the apple draws the Earth, as well as the Earth draws the apple.*'

In *Principia* Newton described universal gravitation and the *Three Laws of Motion*, and his work dominated the scientific view of the physical universe for the next three centuries. Newton showed that the motions of objects on Earth and of celestial bodies are governed by the same set of natural laws, by demonstrating the consistency between his theory of gravitation and Kepler's Laws of Planetary Motion. Newton's famous three laws of motion are as follows. Newton's First Law (the *Law of Inertia*) states that an object at rest tends to stay at rest, and that an object in uniform motion tends to stay in uniform motion, unless acted upon by a net external force. Newton's Second Law states that an applied force on an object equals the rate of change of its momentum with time. The first and second laws represent a break with Aristotelian physics, in which it was believed that a force was necessary in order to maintain motion. The laws instead state that a force is only needed in order to change an object's state of motion. (The SI unit of force is the *Newton*, named in his honour.) Newton's Third Law states that for every action there is an equal and opposite reaction. This means that any force exerted onto an object has a counterpart force, which is exerted in the opposite direction back to the first object. Newton hugely advanced the Scientific Revolution, and the poet Alexander Pope was so overwhelmed by his achievements that he wrote the following epitaph in honour of the great man: '*Nature and nature's laws lay hid in night; / God said "Let Newton be" and all was light.*'

WHY IS HUDSON BAY 'MISSING' GRAVITY?

IN THE 1960s the Earth's global gravity fields were being charted. The force of gravity in the Hudson Bay area was found to be lower than in other parts of the world. Gravity is proportional to mass, so when the mass of an area is somehow made smaller, gravity diminishes. Gravity can vary at different parts of the Earth, which bulges at the Equator and gets flatter at the poles due to its rotation. The Earth's mass is not spread out proportionally, and it can shift position over time. The main cause of the Hudson Bay phenomenon is convection occurring in the Earth's *mantle*. The mantle is a layer of molten rock called magma, between 60 and 124 miles (96 and 200 km) below the Earth's surface. Magma is constantly whirling and shifting, rising and falling, to create convection currents.

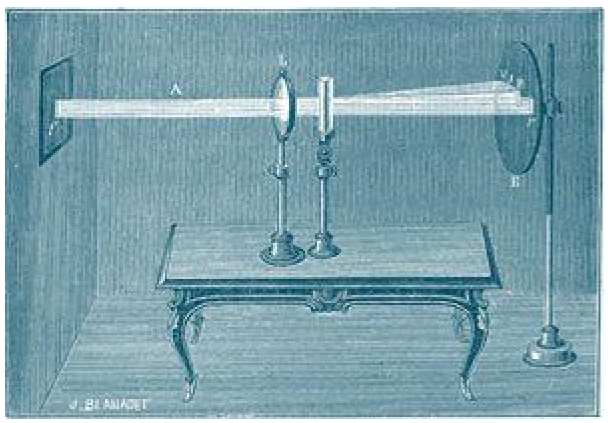
Convection drags the Earth's continental plates down, particularly in this part of Canada, which decreases the mass in that area and so decreases the gravity.

Another important factor is the lasting effect of the Laurentide Ice Sheet, which covered much of North America during a glacial epoch that occurred between 95,000 and 20,000 years ago. This ice sheet was almost 2 miles (3.2 km) thick in most sections, while in two areas of Hudson Bay it was 2.3 miles (3.7 km) thick. Over a period of 10,000 years, the Laurentide Ice Sheet melted, finally disappearing around 10,000 years ago. It left a deep indentation in the Earth. The Earth has 'rebounded' back into shape at less than half an inch (1.25 cm) per year. In the meantime, the area around Hudson Bay has less mass because some of the Earth has been pushed to the sides by the ice sheet. Less mass means less gravity. The Hudson Bay area is going to experience less gravity for millennia. It is estimated that the Earth has to rebound more than 650 feet (200 m) to get back to its original position, which could take about 5000 years. Although sea levels are rising around the world, the sea level along Hudson Bay's coast is dropping as the land continues to recover from the effects of the Laurentide Ice Sheet.

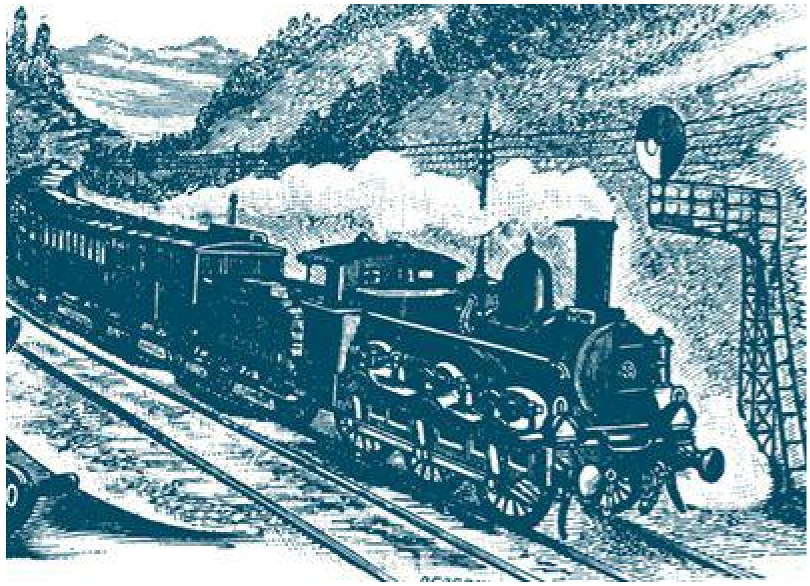
More detailed observations from the GRACE (Gravity Recovery and Climate Experiment) satellite, launched in 2002, suggest that convection in the underlying mantle may be also be contributing to the effect. The GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) satellite since 2009 has provided even better information, measuring accelerations as small as 1 part in 10,000,000,000,000 of the gravity experienced on Earth.

From the mid-1660s Newton conducted a series of experiments on the composition of light, discovering that white light is composed of the same spectrum of colours that can be seen in a rainbow. This work established the

modern study of optics (or the behaviour of light). In 1704 Newton published his *Opticks* which dealt with light and colour. He investigated the refraction of light by a glass prism. Over several years of experimentation, Newton discovered measurable, mathematical patterns in the phenomenon of colour. He found white light to be a mixture of infinitely varied coloured rays (seen in the rainbow and the spectrum), each ray definable by the angle through which it is refracted upon entering or leaving a given transparent medium. With *Opticks*, Newton published a tract on the quadrature of curves (integration) and another on the classification of the cubic curves. *Opticks* was largely written by 1692, but he delayed its publication until his major critics were dead.



Newton made notable contributions to all branches of mathematics, but is especially famous for his solutions to the contemporary problems in analytical geometry of drawing tangents to curves (*differentiation*); and defining areas bounded by curves (*integration*). Newton discovered that these problems were inverse to each other, and also found general methods of resolving problems of curvature, by his *method of fluxions* and *inverse method of fluxions*, equivalent to Leibniz's later differential and integral calculus. By the early 1700s Newton was established as the dominant figure in British and European science.



CHAPTER 5

THE INDUSTRIAL REVOLUTION

RECIPROCATING STEAM PUMPING MACHINE

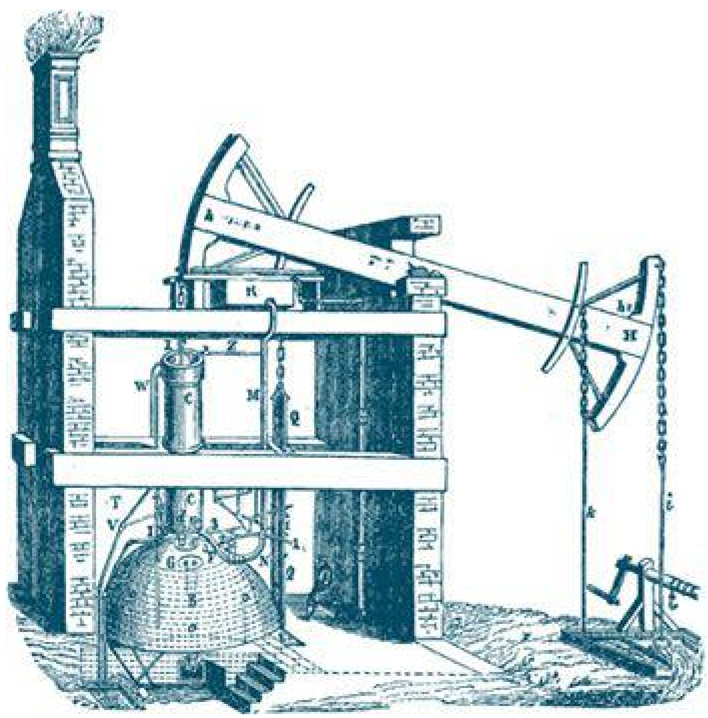
—— 1705 ——

THOMAS NEWCOMEN 1664–1729 AND JOHN CALLEY D.1725, ENGLAND

This invention was to have a profound effect on the ability of mining companies to mine materials at greater depths, thus assisting the dawning Industrial Revolution. It was also the vital stepping stone to Watts's steam engine. Newcomen was a Devon ironmonger who lived near the Cornish tin mines, where flooding limited the depth at which mining could take place. Some of his biggest customers were owners of tin mines, who were looking for an alternative to slow and expensive manual or horse-drawn pumping. Thomas Savery's earlier pump of 1698, based upon the Worcester engine of 1641, just used the vacuum created by condensed steam to pull water up. Savery's device relied upon vacuum and atmospheric pressure to raise water from below, and upon high-pressure steam to force this water to the surface of the mine. It was not a success when used in mines, as there were difficulties in construction due to the limits of current technology. However, Newcomen and his partner John Calley, after years of experiments, came up with a design that worked by creating a vacuum inside a cylinder, which was used to pull down a piston. They then used a lever to transfer the force to the pump shaft that went down the mine. This was the first practical engine to use a piston in a cylinder. Casting the cylinders and getting the pistons to fit was pushing the limit of existing technology, so Newcomen deliberately made the piston marginally smaller than the cylinder and sealed the gap with a ring of wet leather or rope. The engine worked by heating water in its boiler with a coal fire. The steam generated passed through a valve into a large brass cylinder. Cold water was injected into the cylinder, thus cooling down and condensing the steam, and creating a vacuum beneath the piston which pulled the beam down and caused the pumps to move.

However, Savery had taken out a broadly-worded patent for '*raising water and imparting motion to all sorts of mill-work by the impellant force of fire*'. To avoid infringing Savery's patents, Newcomen was forced to go into partnership with him. Newcomen's first working engine was installed at a coalmine near Dudley Castle in Staffordshire in 1712. It had a cylinder

21 inches (53 cm) in diameter and nearly 8 feet (2.4 m) long, and it worked at 12 strokes a minute. It raised 10 gallons (45.5 lit) of water a minute from a depth of 156 feet (47.5 m) – approximately 5.5 horse power. The engine, which used both atmospheric pressure and lowpressure steam, was widely adopted for water pumping in most of Europe and was further improved by Newcomen in 1725. By the time Newcomen died there were at least 100 of his engines in Britain and across Europe. However, while the engines were rugged and reliable and worked day and night, they were inefficient and relatively expensive. In 1769 the Scottish engineer and inventor James Watt invented a steam condenser that vastly increased the efficiency of the engine, and by 1790 the Newcomen engine had been almost completely replaced by the Watt engine. Watt's engine greatly increased the economy of the Newcomen machine by avoiding the loss of steam that occurred in alternate heating and cooling of the engine cylinder. The Black Country Museum in Dudley has reconstructed the 1712 Newcomen engine after much painstaking research and it now displays a full working replica.



INOCULATION

—— 1718 ——

LADY MARY WORTLEY MONTAGU 1689–1762, ENGLAND AND DR ZABADIEL

Many people believe that Edward Jenner invented inoculation, but the Chinese monk Wang Dan was first, around 1000 CE, inventing *variolation*, a type of inoculation. Scabcovered pustules were taken from smallpox survivors, ground up and inhaled through the nose, like snuff. The scabs were taken from patients where the smallpox virus had been weakened, or who had suffered only a mild case of the disease. The English aristocrat and writer Lady Mary Wortley Montagu, who had lost a brother to smallpox, contracted the disease herself in 1715. It left her with facial scarring. In 1716 she accompanied her husband to Constantinople, where he was ambassador. Here she learnt about variolation as practised by the Ottoman Turks. In March 1718 she had the embassy surgeon, Charles Maitland, inoculate her five-year-old son. In 1721, after returning to England, she had her four-year-old daughter inoculated by applying pus from a smallpox sore to a small wound. Mortality from smallpox at this time ranged from around 20–60 per cent. Survivors were usually badly scarred, sometimes blinded and usually suffered chronic pain. However, mortality of those who underwent variolation was only around 1–3 per cent.

The disease exterminated tribes of Africans, American Indians and South American Indians when introduced by the white man. A terrible epidemic in Boston in 1721 affected half of its 10,000 population, and the preacher Cotton Mather recounted how the Africans dealt with the disease in their homelands. They said that they cut open a healthy person's skin and put some of the pus from the disease into the wound. On 26 June 1721, Dr

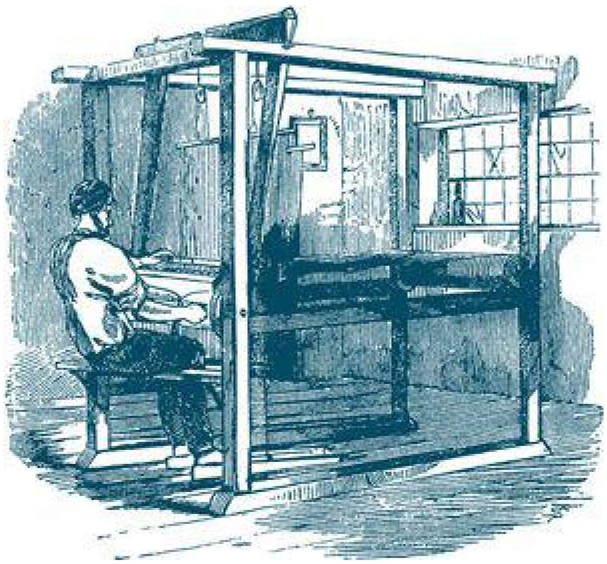
Zabadiel Boylston inoculated his small son and two of his slaves with smallpox. The city elders were horrified, but the patients survived. He then inoculated a further 248 people with beneficial effects. Around the same time the disease hit London and Lady Mary Wortley Montagu convinced the Princess of Wales to support inoculation experiments. She asked the king to pardon six convicts due to be hanged if they would submit to inoculation. They were treated on 9 August 1721 by Dr Charles Maitland and all survived. The treatment worked. Her efforts and its royal acceptance paved the way for Edward Jenner to pioneer vaccination across Europe in the early 19th century.

FLYING SHUTTLE

—— 1733 ——

JOHN KAY 1704–*c*.1779, ENGLAND

This invention made weaving far more efficient by allowing the shuttle carrying the weft to be passed through the warp threads faster and over a greater width of cloth. The invention helped England become the world centre for textile production. John Kay was the son of a wool manufacturer in Bury, Lancashire, who became the manager of one of his father's mills. Kay developed skills as a machinist and engineer, and made many improvements to the machines in the mill. In May 1733 Kay patented his '*New Engine of Machine for Opening and Dressing Wool*'. This machine included the revolutionary *Flying Shuttle* device: a *wheeled shuttle* for the hand loom. Before the invention of the flying shuttle, a weaver on a hand loom had to pass the shuttle, which contained the weft thread, through the warp threads by hand. Thus it was only possible for cloth to be woven up to a maximum of the width of a man's body across his outstretched arms. This was because he had to pass the shuttle backwards and forwards, from hand to hand. If a wider cloth was needed, two weavers threw the shuttle to each other across a *broad loom*.



‘IT HAS ALL BEEN MOST INTERESTING’

LADY MARY Wortley Montagu has been called ‘*the most interesting Englishwoman of her century*’ and her wit is revealed in her remark: ‘*The one thing that reconciles me to the fact of being a woman is the reflection that it delivers me from the necessity of being married to one*.’ There is also a story that Lady Mary was told at the opera that her hands were dirty, and she answered: ‘*You should see my feet!*’ She is buried in London, and her dying words are supposed to have been: ‘*It has all been most interesting*.’ There is a wonderful monument commemorating her achievement in Lichfield Cathedral.

‘A SPEED WHICH CANNOT BE IMAGINED’

KAY CALLED his invention a ‘wheeled shuttle’, but others used the name ‘fly-shuttle’, and later ‘flying shuttle’, because of its continuous speed, especially when a young worker was using it in a narrow loom. It achieved ‘*a speed which cannot be imagined, so great that the shuttle can only be seen like a tiny cloud which disappears the same instant*.’ Roland de la Platière, *Encyclopédie Méthodique*, 1785

Kay’s invention put the shuttle on wheels and controlled it with a *driver*. The weaver operated the shuttle by pulling a cord attached to the driver.

When this cord was pulled to the left, the driver caused the shuttle to shoot (*fly*) through the warp in the same direction. Pulling the cord to the right sent the shuttle back. Now the shuttle, containing the thread, could be shot backwards and forwards across a much wider bed. The flying shuttle also allowed the thread to be woven at a faster rate, thus enabling the process of weaving to become faster. Since it more than halved labour costs – on a broad loom, a second worker was not needed – the textile industry was quick to adopt Kay's invention. Unfortunately for Kay, the manufacturers formed an association which refused to pay him any royalties. He lost all of his money in legal battles to defend his patent. He eventually moved to France to set up his machines there, and the beginning of the mechanization of French textile production is traditionally dated to 1753, with their widespread adoption of the flying shuttle. Most of these new shuttles were copies, however, not made by Kay. John Kay unsuccessfully tried to enforce his manufacturing monopoly, and quarrelled with the French authorities, dying penniless.

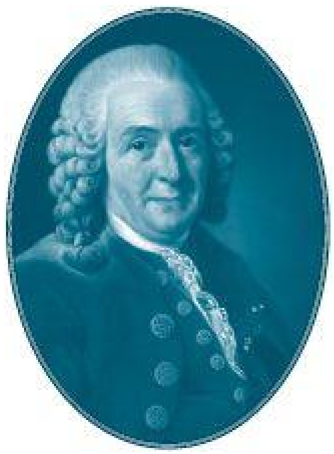
TAXONOMY – THE NAMING OF LIFE

—– 1735 —–

CARL LINNAEUS 1707–1778, SWEDEN

The Swedish naturalist and physician Linnaeus (Carl von Linné or Carolus Linnaeus) is often called the 'father of taxonomy'. His system for naming, ranking and classifying organisms is still in use today, and his ideas about classification have influenced generations of biologists and botanists. Linnaeus was the originator of today's taxonomic classification of all living things. In his time some mushrooms were edible, some that looked similar might cause illness, while others could kill. Apart from various local names, however, they were all simply called mushrooms. Linnaeus realized that the casual nomenclature of the day could not accurately describe all the mushroom species of Scandinavia, let alone the latest discoveries from the New World. Other botanists had tried to name plants and animals with different approaches, but with little success. For instance, one of the agreed 'formal' names for the tomato was '*Solanum caule inerme herbaceo, foliis pinnatis incisis, racemis simplicibus*.' This meant 'Solanum with smooth herbaceous stem, incised pinnate leaves and simple inflorescence'. Thanks

to Linnaeus’s later taxonomy it is now formally identified as the species *Solanum lycopersicum*; in the genus *Solanum*; in the family Solanaceae; in the order Solanales; in the kingdom of Plantae. Similarly, the African marigold is classified as the species *Tagetes erecta*; in the tribe Tageteae; in the subfamily Asteroideae; in the family Asteraceae; in the order Asterales; in the kingdom of Plantae.

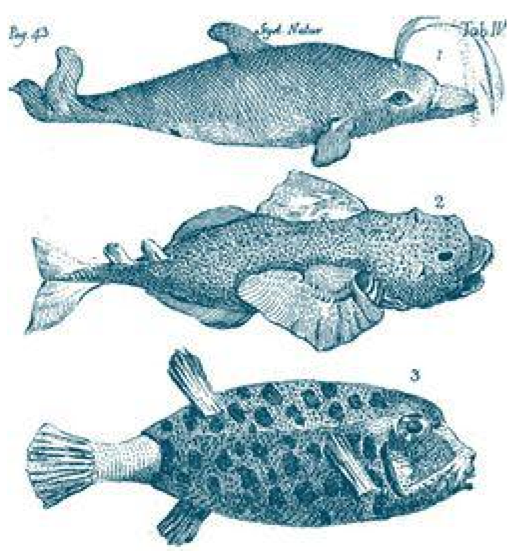


As a young man, Linnaeus travelled through Lapland, making careful observations of geography and plants, before becoming a professor at Uppsala University. He never travelled abroad again, but relied upon his students to collect specimens of plants and animals for him, while he formulated a new classification system and nomenclature. He adopted the motto ‘*God created, Linnaeus organized*’. To determine a plant species, he began with a specimen from a garden, an herbarium sheet (a dried plant mounted on paper) or an illustration, and described it fully. After that, he collected additional specimens that represented the species. Linnaeus now successfully introduced the system of classifying organisms. His system includes (in descending order) *kingdom, phylum, class, order, family, genus* and *species*. The genus and species name of any particular organism became its scientific name in his new framework of *binomial nomenclature*. He also adopted the practice of associating a species with a ‘type specimen’, the example by which the species is identified. For example, the Asteraceae (formerly Compositae) family, also known as the aster, daisy or sunflower family, is the largest family of vascular plants. There are over 22,750 accepted species in this family, spread across 1620 genera and 12

sub-families. The largest genera are *Senecio* (1500 species), *Vernonia* (1000 species), *Cousinia* (600 species) and *Centaurea* (600 species).

INSANITY AND BEETLES

LINNAEUS HAD students and followers all over the world who sent him specimens. What has survived to the present day is the emphasis on type specimens, and the practice of giving priority to the first person to name a new species. Thus Daniel Rolander, labouring in the jungles of Surinam, searched for coveted cochineal beetles in the hopes that the beetle would be named after him. Used to make brilliant red dyes, the insects lived on, and fed on, a New World cactus. Rolander lovingly tended his prize specimens on the long voyage home, and delivered the beetles to Linnaeus's greenhouse. However, Linnaeus was out and his gardener, according to historian Amy Butler Greenfield, '*knew a grubby and infested plant when he saw one*'. By the time that Linnaeus returned home, his gardener had removed and squashed every last male and female insect. Linnaeus suffered a migraine, and Rolander went completely insane. The cochineal beetle could have been called *Dactylopius rolander* but is now the species *Dactylopius coccus*; in the genus *Dactylopius*; in the family Dactylopiidae; in the superfamily Coccoidea; in the order Homoptera; in the class Insecta; in the phylum Arthropoda; in the kingdom Animalia; in the domain or taxon Eukaryota.



When Linnaeus first released his *Systema Naturae* in 1735, it was only 14 pages long. He grouped animals into the categories of *Quadrupedia* (fourfooters), *Aves* (birds), *Amphibia* (including reptiles), *Pisces* (fish), *Insecta* (insects) and *Vermes*. Vermes included worms, snakes and slimy, slithery creatures that did not fit easily into any other category. Mankind was classed in quadrupedia, which angered many, especially preachers and others of a religious bent. The last edition of *Systema Naturae* published during his lifetime (the 12th) was 2300 pages long. Before Linnaeus died, he had catalogued around 7700 plants and 4400 animals. He recommended that his gravestone should read: 'Prince of Botanists'. Wisely, Linnaeus had created a naming system that could grow – thousands of new named species are still described each year. His 'kingdoms' have recently been reworked, and DNA sequencing has readjusted some relationships, but his original naming system has persisted largely intact.

HOW MANY SPECIES FIT INTO AN ARK?

THE EVER-GROWING list of species presented the religiously devout Linnaeus with a problem, namely how everything could have fitted in the Biblical ark. He solved the problem by substituting an island for an ark. It was believed that the whole Earth was covered by the waters of the Great Flood, but Linnaeus argued that the one exception to the universal ocean was a large island, which acted both as Noah's Ark and the Garden of Eden. The discovery of Mount Ararat, assumed by many to be the ark's landing site, suited his purposes perfectly. It rose to a great height, and conveniently provided all the necessary climate zones for plants and animals that had to survive the Biblical deluge.

Emperor Akihito, 125th emperor of Japan and an ichthyologist, has praised binomial nomenclature's ability to give scientists a universal basis for taxonomy. An August 2011 news release stated that scientists have yet to discover, or classify, almost 90 per cent of the plant and animal species on Earth, which is estimated to be home to around 8.7 million species (6.5 million on land and 2.2 million in the sea). Only 1.2 million species have been formally described and named so far. The results suggested that 86 per cent of existing species on land and 91 per cent of species in the ocean still await description, and the project's leader concluded: '*With the clock of extinction now ticking faster for many species, I believe speeding the inventory of Earth's species merits high scientific and societal priority*'. Some UN studies suggest that the world is facing the heaviest rate of species loss, owing to land clearing, pollution, climate change and other factors, since the dinosaurs vanished 65 million years ago.

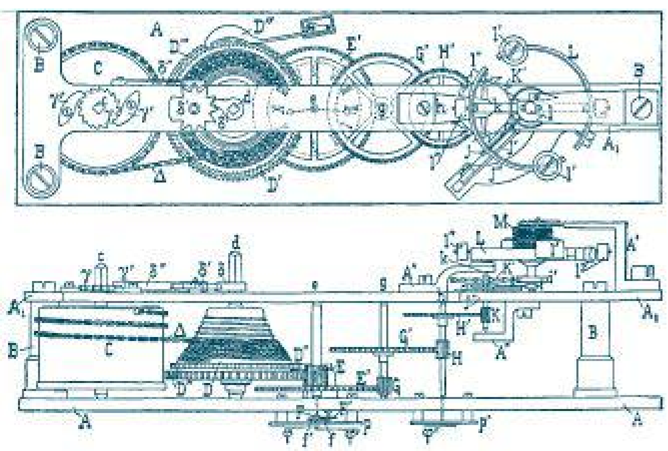
MARINE CHRONOMETER

—– 1761 —–

JOHN HARRISON 1693–1776, ENGLAND

While the quadrant (or cross staff) (and later the sextant of 1757) allowed the measurement of latitude at sea, longitude (the east-west position) could only be measured by reference to an accurate timepiece, or chronometer, onboard ship. While the development of the Mercator projection represented a major breakthrough in nautical cartography in the 16th

century, navigational and surveying techniques were not compatible with its use in navigation. The first problem was the impossibility of determining the longitude at sea with adequate accuracy. The second difficulty was that magnetic directions, instead of geographical directions, were used in navigation. Only when the marine chronometer was invented, and the spatial distribution of magnetic declination known, could the Mercator projection be fully adopted by navigators. (Magnetic declination is the angle between magnetic [compass] North and 'true North', and varies according to position and time.)



On voyages, cumulative errors in *dead reckoning* frequently led to shipwrecks and lost lives. Formerly known as 'deduced reckoning', this is the process of calculating one's current position by using a previously determined position (or *fix*), and advancing that position based upon known or estimated speeds over elapsed time, and course. Avoiding maritime tragedies became an imperative in this 'Age of Sail', as trade and navigation were massively expanding as a result of the Industrial Revolution. In 1714, the British government offered, by Act of Parliament, £20,000 for a solution which could provide a measurement of longitude to an accuracy within half-a-degree (two minutes of time). The methods would be tested on a ship. The clockmaker John Harrison, who had made some of the most accurate pendulum clocks the world had ever seen, developed a series of timepieces to solve the problem. Marine chronometers must be corrosionproof, shock-proof and unaffected by the sailing ship's constant motion, temperature swings and changes in gravitational force. Constructed between 1730 and 1735, *H1* (short for Harrison 1) was a portable version of his precision wooden clocks, with the moving parts controlled and

counterbalanced by springs so that it worked independently of the force of gravity. He tested it at sea, and carried on inventing and innovating with *H2* and *H3*. His *H4* of 1761 looked like a very large pocket watch; on a voyage to Jamaica it lost only five seconds. Other successful trials followed, and versions of his chronometer were adopted across the world. For the first time, ships were able to navigate accurately using longitude.

THE CAPTAIN COOK EXPERIENCE

CAPTAIN JAMES Cook had set out on his second voyage of discovery using Larcum Kendall's *K1*, a copy of *H4*, to determine his longitude readings. He returned in July 1775, after a voyage of three years, which ranged from the Tropics to the Antarctic. The daily rate of time loss of *K1* never exceeded eight seconds (corresponding to a distance of just two nautical miles at the equator) during the entire voyage and Cook called the watch '… *our faithful guide through all the vicissitudes of climates*'. Captain William Bligh was the sailing master, and he used the *K1* to navigate on Captain Cook's third voyage, when Cook was murdered at Hawaii in 1779. Bligh's *K2* chronometer was seized by the mutineers on HMS *Bounty* in 1789. Bligh was given just an old quadrant and a compass, but no charts or sextant, but in a small ship's boat he then navigated the seemingly impossible 3618 nautical miles (6700 km) to Timor, taking 47 days. The surviving *Bounty* mutineer, John Adams, sold the *K2* in 1808, and along with a *K1* and a *K3* it can be seen on display in the Royal

Observatory, Greenwich. The priceless Harrison *H1* to *H4* chronometers can be seen in the National Maritime Museum, Greenwich.

SPINNING JENNY

—— 1764 ——

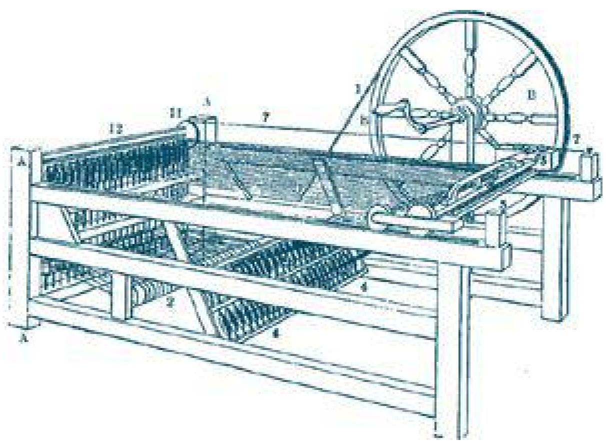
JAMES HARGREAVES 1720–1778, ENGLAND

This was the first machine to improve upon the spinning wheel, which had been used in Europe since the 13th century to produce yarn for textiles. Several important inventions facilitated the handling of large quantities of harvested cotton, and the massive growth of the English textile industry. In a relatively short timeframe there was the introduction of the flying shuttle, spinning frame, cotton gin, spinning mule and spinning jenny. The demand for cotton yarn greatly outstripped supply, and the existing one-thread spinning wheel could not keep up. (In general, women spun thread, and men were weavers of the thread into textiles.) In 1764, a British carpenter and weaver named James Hargreaves invented a hand-powered multiple spinning machine to improve upon the spinning wheel. Hargreaves was never taught to read and write, but his *Spinning Jenny* (possibly named after his wife) was a work of genius. It used eight spindles, instead of the single one found on the spinning wheel. It mirrored the simple wheel, the *rovings* (see box) being clamped, with a frame moving forward, stretching and thinning the rovings. A wheel was rapidly turned as the frame was pushed back, the spindles rotated, twisted the rovings into yarn and collecting it on the eight spindles. Later models had up to 128 spindles. However, the thread that the machine produced was coarse and lacked strength, making it suitable only for the filling of *weft*, the threads that are woven across the warp.

ROVING, CARDING AND TEASELS

A *ROVING* is a long and narrow bundle of fibre, normally used for spinning woollen yarn. A roving was created by *carding* the fibre, which was then drawn into long strips ready for spinning into threads. Carding is a mechanical process, which breaks up unorganized clumps of fibre, aligning the individual fibres so that they are more or less parallel with each other,

ready for spinning. The word is derived from the Latin *carduus* meaning teasle, as dried teasle plant heads were first used to comb the raw, tangled wool into long bundles.



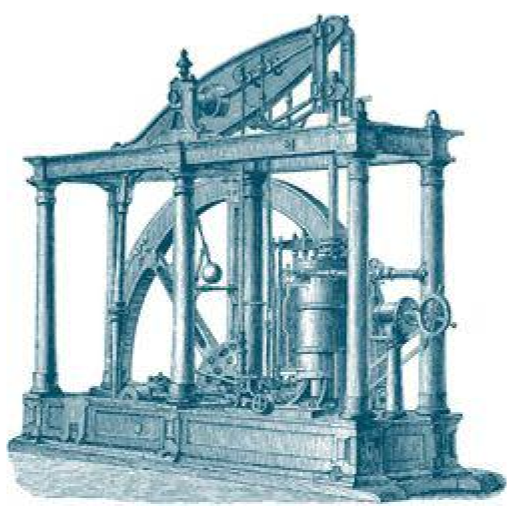
James Hargreaves made a number of spinning jennies and started to sell them in the local area. The jenny was initially welcomed by the hand spinners, but when the price of yarn fell, their mood altered. Since each machine was capable of doing the work of eight people, other spinners were angry about the 'unfair' competition. In 1768 a group of spinners broke into Hargreaves's house and destroyed his machines. Opposition to the machine caused Hargreaves to move from Blackburn to Nottingham, where the cotton hosiery industry benefited from the increased provision of suitable yarn. Hargreaves did not apply for a patent for his 16-spindle spinning jenny until 1770. The courts had rejected his patent application for his eight-spindle spinning jenny because he had made and sold several examples over too long a period before he filed for a patent. Others copied Hargreaves's ideas without paying him any money. By the time he died, there were over 20,000 spinning jennies in use in Britain, many with 80 threads, thereby bringing an 80-fold efficiency increase over a single spindle spinning wheel.

STEAM ENGINE IMPROVEMENTS

—— 1769 ——

JAMES WATT1 1736–1819, SCOTLAND

The innovation of a separate condenser made engines far more efficient, and enabled them to drive many more machines than just steam pumps, so accelerating the pace of the Industrial Revolution. An instrument maker and engineer, in 1763 Watt was sent a Newcomen steam engine for repairs, and he realized how he could make it far more efficient. A lot of heat was lost when condensing the steam, as this cooled the cylinder. This did not matter unduly at a colliery, where unsaleable small coal (slack) was available, but it significantly increased the mining costs where coal was not so readily available, as in Cornwall. Watt realized that designs based on the Newcomen engine wasted energy by repeatedly cooling and re-heating the cylinder. He therefore introduced a design enhancement, a condenser separate from the main cylinder, which avoided this waste of energy and radically improved the power, efficiency and cost-effectiveness of steam engines. It was patented in 1769. Not having the funds to market his new design, he took his ideas to Matthew Boulton in 1775. Boulton was a wealthy businessman who now undertook manufacture of Watt's machines, and sold them to colliery owners to pump water from their mines. Watt's steam pump was four times more powerful than a Newcomen engine. In 1781 Watt produced a rotary-motion steam engine. His earlier machine, with its up-and-down pumping action, was ideal for draining mines, but this new steam engine could be used to drive many different types of machinery. By 1783 Richard Arkwright was using Watt's steam-engine in his textile factories. By 1800 there were over 500 of Watt's machines in Britain's mines and factories.



In 1775 Watt was granted a patent by Parliament that prevented anybody else from making a steam-engine like the one he had developed. For the following 25 years, the Boulton and Watt company had a virtual monopoly over the production of steam engines. New iron-casting techniques pioneered by the Coalbrookdale Company in the 1720s had allowed far bigger and much cheaper cylinders than the brass ones previously used. Boulton & Watt became the most important engineering firm in Britain, and probably the world, meeting considerable demand. Initially this came from Cornish mine owners, but later extended to paper, flour, cotton and iron mills, as well as distilleries, canals and waterworks.

WATT AND HORSEPOWER

WATT CHARGED his customers a premium for using his steam engines. To justify this, he compared his machine to a horse. Watt calculated that a horse exerted a pull of 180 pounds (82 kg), so when he designed a machine, Watt described its power in relation to a horse, i.e. '*a 20 horse-power engine*'. Watt then worked out how much each company saved by using his machine rather than a team of horses. The company had to pay him one third of this figure every year, for the next 25 years. Thus Watt developed the concept of *horsepower*, and the SI unit of power, the *watt*, is named after him.

MODERN FACTORY SYSTEM AND WATER FRAME

—– 1771 —–

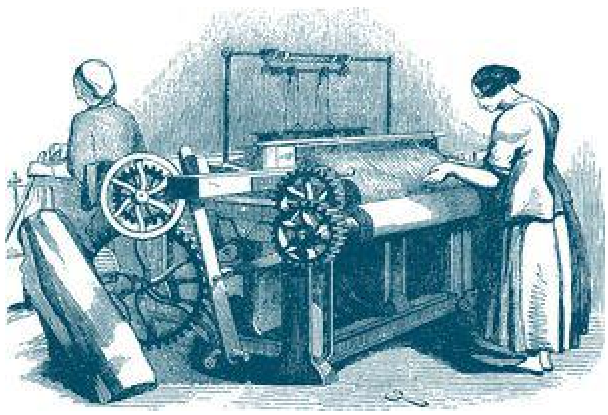
RICHARD ARKWRIGHT 1732–1792, ENGLAND

Arkwright's innovations and inventions were a catalyst for the Industrial Revolution, and his factory methods were copied across the world. In 1762 Arkwright had started a wig-making business, which involved him in travelling around the country collecting people's discarded hair. Arkwright heard about the attempts being made to produce new machines for the textile industry. He also met John Kay, who had tryied to produce a new spinning machine with Thomas Highs. They had run out of money, and had been forced to abandon the project. Arkwright now helped Kay to produce the *spinning frame*, in which three sets of paired rollers turned at different

speeds. The rollers produced yarn of the correct thickness, while a set of spindles twisted the fibres firmly together, producing a far stronger thread than that made by James Hargreaves's spinning jenny. The resultant cotton thread was far more suitable for the 'warp', the long threads needed for making cloth. English cotton usually had linen warps and cotton wefts as cotton thread could not be made strong enough for use as warp. Linen, made from the fibres of flax, was labour-intensive to produce and therefore expensive. Now cotton warps and wefts could be used, and textiles made more cheaply of pure cotton. Arkwright's new spinning frame was too large to be operated by hand, and so it was decided in 1771 to employ the power of the waterwheel, with the machine becoming known as the *water frame*. This machine took the place of many manual workers and consequently drove down the price of cotton. In 1775 Arkwright took out a patent for a carding machine, to be used in the first stage in the spinning process, replacing the handcarding and turning raw cotton buds (or wool) into a continuous shank of cotton (or wool) fibres which could then be spun into yarn.

Arkwright built new, hugely profitable textile factories, using the new steam engines of Boulton and Watt to pump water to the millrace of a waterwheel. From the combined use of the steam engine and his new machinery, the *power loom* was eventually developed in many forms. In his mills, the whole process of yarn manufacture was carried on by one machine, further complemented by division of labour, greatly improving efficiency. He preferred weavers with large families, so that the women and children could working in his spinning-factory, while the weavers worked at home turning the yarn into cloth. His employees worked from six in the

morning to seven at night. Two-thirds of Arkwright's 1900 workers were children from the age of 6 years old upwards. Like most factory owners, Arkwright was unwilling to employ people over the age of 40, as they were slower. Richard Arkwright died in 1792, and was said to be worth over £500,000, or £50 million in today's terms using the retail price index. Using average earnings as the index of his estate's value, he left £568 million.



THE WEALTHIEST COMMONER IN BRITAIN

THE SON OF Arkwright, another Richard Arkwright (1755–1843), was in his twenties when he bought the Manchester mill from his father. In 1781 and 1787 he bought two more mills. Inheriting his father's properties and aged 37, the younger Arkwright decided to concentrate on landed property and banking. He disposed of most of his mills, fortunately just before the post-Napoleonic Wars recession set in. He made loans to people such as Georgiana, duchess of Devonshire, who was anxious to conceal her gambling debts from her husband. In 1809, Arkwright bought the Herefordshire estate of Hampton Court for the incredible sum of £230,000, for his son John. During the purchase of Sutton Hall in Temple Normanton, the bidding rose quickly. The auctioneer became concerned that the unknown bidder sitting in his simple buff coat and fawn breeches might not be able to pay the deposit, let alone the capital sum. Richard Arkwright then stood up and took from his pocket a banknote for £20,000 stating: '*There are only four of these printed, the other three are at home*'. He bought the mansion. Arkwright kept such a low profile that *The Times* carried no obituary when he died from a sudden stroke, aged 87. The insignificant notice of his death made no reference to his extensive property holding, nor

of his being easily the wealthiest commoner in Britain, with an estate worth over £3.8 million. In today's money that would be more £316 million using the retail price index, or £2.97 billion using average earnings. Bankers always prosper. It was ever thus…

OXYGEN THEORY OF COMBUSTION

—— 1778 ——

Antoine Laurent de Lavoisier 1743–1794, France

Lavoisier's contributions are considered the most important in advancing chemistry in the 18th century to the equivalent level already reached in physics and mathematics. A radical French nobleman and chemist, as a student he stated '*I am young and avid for glory*.' Lavoisier won a prize for an essay about lighting the streets of Paris, and designed a new method for preparing saltpetre. Lavoisier demonstrated with careful measurements that transmutation of water to earth was not possible, and that the sediment observed from boiling water derived from the container. He burned phosphorus and sulphur in air, and showed that the products of the combustion weighed more than the original constituents. The weight gained came from matter lost from the air. Thus he established Lavoisier's *Law of Conservation of Mass*.

When Lavoisier began his experiments with combustion and respiration, chemistry was still in the very early stages of development. There was plenty of empirical information, but very little theoretical basis and no formal scientific language. Many characteristics of acids, alkalis, salts and metals were known so that they could usually be distinguished, but gases

were hardly known to exist. Repeating Joseph Priestley’s discoveries, Lavoisier demonstrated that air is composed of two parts, one of which combines with metals to form *calxes* (residual substances, sometimes in the form of fine powder). In *Considérations Générales sur la Nature des Acides* (1778), he demonstrated that the ‘air’ responsible for combustion was also the source of acidity. In 1779, he named this portion *oxygène* (Greek for ‘acid-forming’), and the other *azote* (Greek for ‘no life’). Lavoisier also discovered that the inflammable gas discovered by Cavendish, which he termed *hydrogène* (‘waterforming’) combined with oxygen to produce dew which appeared to be water. Lavoisier showed that water could be turned back into hydrogen and oxygen when passed through a red-hot gun barrel. The oxygen also reacted with the iron to form rust.

In *Reflexions sur le Phlogistique* (1783), Lavoisier demonstrated the current ‘*phlogiston theory*’, which postulated that materials released a mysterious substance called phlogiston when they burned (see box), to be inconsistent. In *Méthode de Nomenclature Chimique* (1787), he invented the system of chemical nomenclature still largely in use today, including names such as sulphuric acid, sulphates and sulphites. His *Traité Élémentaire de Chimie* (1789) was the first modern chemical textbook, and presented a unified view of new theories of chemistry. It contained a clear statement of the Law of Conservation of Mass, showing that the mass of the reactants had to equal the mass of the products, and thus disproved the existence of phlogiston. The book also included a list of ‘elements’, or substances that could not be broken down further, including oxygen, nitrogen, hydrogen, phosphorus, mercury, zinc and sulphur. In the work, Lavoisier emphasized the observational basis of his chemistry: ‘*I have tried…to arrive at the truth by linking up facts; to suppress as much as possible the use of reasoning, which is often an unreliable instrument which deceives us, in order to follow as much as possible the torch of observation and of experiment*.’

Lavoisier demonstrated that breathing organisms disassemble and reconstitute atmospheric air, in the same manner as a burning body. With Laplace, he used a calorimeter to estimate the heat evolved per unit of carbon dioxide produced. They found the same ratio for a flame and animals, indicating that animals produced energy by a type of combustion when breathing. Lavoisier also discovered that diamond is a crystalline form of carbon. The revolution in chemistry which he brought about was a

result of a conscious effort to fit all experiments into the framework of a single theory.

THE PHLOGISTON THEORY

THIS WAS first proposed in the late 17th century by the German physician Johann Becher (who referred to it as '*inflammable earth*'). The theory postulated that in all flammable materials the elusive substance *phlogiston* is present, a substance without colour, odour, taste or weight. This was what was given off when materials were burned. All materials were thought to comprise three basic parts: phlogiston, impurities and the purest form of the original material. Anything that could be burned to nothing – such as charcoal or sulphur – was considered to consist entirely of phlogiston. However, a substance like wood, for example, leaves ash when burned, and it was thus believed that wood was composed of pure wood (ash) and phlogiston. Iron on the other hand must consist of rust, the pure form of the metal, and phlogiston. *Impurities* arose where the remains could not be defined as either the pure material or phlogistonated air. Gases that dissolved in water were an example of this kind of impurity, materials that did not meet the criteria of either the purest form of the material or phlogiston.

HOW NOT TO TREAT A GENIUS

ALTHOUGH A Liberal, Lavoisier was branded a traitor during the French Revolution by Robespierre's Assembly, with the specific charge of

adulterating tobacco. He had also intervened on behalf of a number of foreign-born scientists including the brilliant mathematician Lagrange. A few years earlier Lavoisier had been shown an invention by the scientist and radical politician Jean-Paul Marat, which Lavoisier branded preposterous. Marat led the agitation for Lavoisier to be guillotined. It is alleged that the appeal to spare his life, so that he could continue his experiments, was cut short by the judge: '*La République n'a pas besoin de savants ni de chimistes; le cours de la justice ne peut être suspendu*.' ('The Republic needs neither scientists nor chemists; the course of justice cannot be delayed.') Lagrange lamented his death, writing: '*Cela leur a pris seulement un instant pour lui couper la tête, mais la France pourrait ne pas en produire une autre pareille en un siècle*.' ('It took them only an instant to cut off his head, but France may not produce another such head in a century.') Eighteen months after his public execution, Lavoisier was exonerated by the French government. His private belongings were delivered to his widow, with a brief note attached, reading '*To the widow of Lavoisier, who was falsely convicted*.'

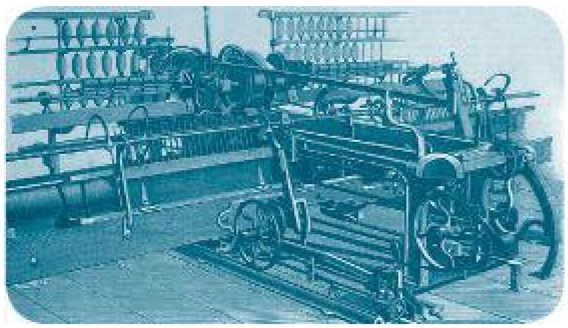
SPINNING MULE

—— 1779 ——

SAMUEL CROMPTON 1753–1827, ENGLAND

The spinning mule led to a massive increase in the processing of raw cotton into yarn. Its arrival meant the cotton boom had begun. Crompton was a mill worker who had learned to spin using a spinning jenny, but he recognized that one of the problems with it was that the thread was not strong enough, and it kept breaking. It took Crompton more than five years to invent and perfect the *spinning mule*. Crompton supported his invention by working as a violinist at the Bolton Theatre for pennies a show, spending all his wages on his machine. It combined the moving carriage of the spinning jenny with the rollers of Arkwright's *water frame*, producing a very fine and even thread, suitable for spinning yarns for making even fine muslin. The mule produced strong, thin yarn, suitable for any kind of textile, and was first used to satisfy the tremendous demand for cotton, then other fibres. It spun textile fibres into yarn by an intermittent process: in the draw stroke, the roving was pulled through and twisted; on the return it was

wrapped onto the spindle. Although Crompton used Hargreaves's ideas of spinning multiple threads and of attenuating the roving with rollers, it was he who put the spindles on the carriage and fixed a creel of roving bobbins on the frame. Both the rollers and the outward motion of the carriage removed irregularities from the roving before it was wound on the spindle. It gave great control over the spinning process, and enabled the spinner to use any type of yarn.



COTTON MILLS AND THE SLAVERY BOOM

TO FEED the hungry north of England cotton mills, a parallel slave boom occurred on the plantations of the southern states of America. By the 1850s some three-quarters of all Lancashire cotton was supplied by the slave states of the American South. This reliance on the United States left the mills vulnerable. If the American cotton crop failed or the supply was interrupted, then the consequences were felt across the world, but above all in Lancashire. Sarah Redmond, a free African-American, spoke at the Manchester Athenaeum in Lancashire in 1859, calling upon women in particular to raise public opinion and support the work of the American abolitionists. She reminded them of the terrible abuses suffered by female slaves, and that Manchester's own prosperity was based on slave-grown cotton: '*We have states where, I am ashamed to say, men and women are reared, like cattle, for the market. When I walk through the streets of Manchester and meet load after load of cotton, I think of those 8000 cotton plantations on which was grown the 125 millions of dollars' worth of cotton which supply your market, and I remember that not one cent of that money ever reached the hands of the labourers*.' In the American Civil War, the North blockaded southern ports so goods could not be brought in or out, and the export of slave-grown raw cotton dried up. Liverpool traders also

suspended trade, waiting for prices to increase. This led to the *Lancashire cotton famine* (1862–3) which was a period of incredible hardship when many thousands of Lancashire mill workers lost their jobs.

However, Crompton was poor and did not have enough money to develop his invention in order to patent it. He tried to raise money by playing his home-made violin at concerts. Eventually he was forced to sell the rights and returned to weaving. Richard Arkwright patented it, and the spinning mule was quickly adopted by the textile industry. In March 1792, an angry crowd of spinners broke into Grimshaw's factory in Manchester and destroyed all the spinning mules which had been installed there. When Arkwright's patents expired, the mule was developed by several other manufacturers. In 1812, in a petition to Parliament to try and gain recompense for his invention, Crompton reported that of the cotton spindles in daily use in Britain, 4.6 million were spinning on mules while only around 470,000 were on other types of spinning machine. In Bolton Museum can be seen the only surviving spinning mule made by its inventor, dating from around 1802.

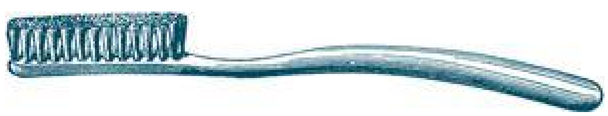
TOOTHBRUSH

—— 1780 ——

WILLIAM ADDIS 1734–1808, ENGLAND

The Babylonians used 'chewing sticks' for oral hygiene around 3500 BCE, which were basically twigs with frayed ends. In India, the twigs of the neem tree were chewed until soft and then splayed to brush the teeth. In 1223, Chinese monks were recorded as cleaning their teeth with brushes

made of horsetail hairs attached to an ox-bone handle. The first bristled toothbrush originated in China around 1500, the bristles coming from the necks and shoulders of pigs that lived in colder climates, where they grew longer, thicker hair. In 1690 we first come across the word '*toothbrush*' in the English language, when the antiquary Anthony Wood records buying one. In 1770 William Addis was jailed for causing a riot. While in prison he decided that the method used to clean teeth, rubbing a rag with soot and salt across the teeth, could be improved. Addis found a small animal bone, drilled small holes in it, obtained some bristles from a guard, tied them in tufts, passed the tufts through the holes in the bone, and glued them in place. Another of his prototypes used horsehair inserted in holes bored into bone and kept in place by thin wire. Addis was the first known massproducer, starting a family firm selling toothbrushes, with handles carved out of cattle bones. He soon became very rich. By 1845 brushes were still being handproduced from bone or ivory with hair or bristle filaments. The bones used to make the brush backs and handles were from ox thighs and rumps, which had been boiled to remove fat and grease. The ends of the bones were cut off and sold to button-makers, as only the mid-sections were used by brush-makers.



Fifty-three processes went into the making of an Addis toothbrush and the bristle-filling was mostly done by women working in their own homes. Pig bristle was used for cheaper toothbrushes, and badger hair for the more expensive ones. In the 1860s Addis became one of the first manufacturers in the UK to use an automated manufacturing system, and in 1869 the first Addis toothbrush handle was made by machine. During the First World War, Addis supplied troops with toothbrushes, thereby creating a national 'habit' of teeth cleaning. By 1926 the company was producing 1.8 million toothbrushes per year. 1927 saw the introduction of the first plastic-handled toothbrushes (made of celluloid), and brushes were filled with bristles mechanically.

TEETH THAT SHINE LIKE IVORY

‘*Both Sexes take great care of their teeth, more than I have seen in any country. They are constantly cleaning them with green hazelshoots and then rubbing them with woollen cloths until they shine like ivory. For their better preservation, they abstain from hot meats, and eat only such as are cold, warm, or temperate*.’ Giraldus Cambrensis, *The Description of Wales*, 1188

In the Second World War, a million brushes were supplied to the armed forces, and in 1940 the first nylon toothbrushes with plastic handles and plastic bristles were launched under the WISDOM brand. In 1938, DuPont had manufactured the first nylon bristle toothbrushes. Animal bristle was not an ideal material as it harboured bacteria and did not dry well, with the bristles often falling out. Bonehandled production ended at Addis in 1947. The electrical toothbrush was first marketed in the United States in 1960 by Squibb, and called the Broxodent. General Electric introduced a rechargeable cordless toothbrush in 1961. Interplak was the first rotary action electrical toothbrush for home use, and it was introduced in 1987. In 1996, a management buy-out saw the end of the family-run Addis firm after 216 years, and three years later it was subject to a German takeover by EMSA Holding AG.

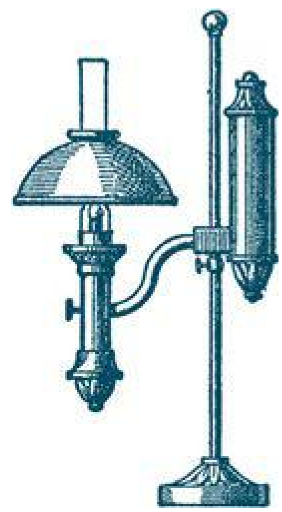
OIL LAMP

—— 1782 ——

François Pierre Aimé argand 1750–1803, France

The ‘Argand lamp’ became the standard source of illumination in homes, shops and factories during the Industrial Revolution. The use of oil lamps began thousands of years ago, and their first description using crude mineral oil was given by Rhazes in his ninth-century *Book of Secrets*. Lamps with a refillable reservoir and a fibrous wick, giving a controlled flame, were found in Egypt and China, and the Greeks had developed practical lamps with handles around 700 BCE. Early lamps were not bright enough to carry out any detailed work at night, however. The first scientifically constructed and vastly improved oil lamp was invented in 1782, and patented in 1784 in England by the Swiss scientist Aimé Argand. This heralded the first basic change in lamp design for thousands of years, and applied a principle that was later adapted to gas burners.

The Argand burner consisted of a hollow cylinder within a circular wick, allowing air to flow both inside and outside of the flame at the upper edge of the fuel-soaked wick. The wick was housed between two concentric metal tubes. The inner tube provided a passage through which air rose into the centre to support combustion. A glass chimney ensured a greater draught of air up the centre and the outside of the wick for even and proper combustion of the oil. It also enhanced the brilliance of the flame by sheltering it from side draughts. The Argand lamp gave about ten times the light of earlier oil lamps of the same size, as well as a cleaner flame, but its oil consumption was greater. The light was also much brighter than a candle (by a factor of between five and ten), and was therefore cheaper than using candles. A mechanism for raising and lowering the wick allowed some adjustment and optimization. Eventually, Argand lamps with as many as ten concentric wicks were manufactured.



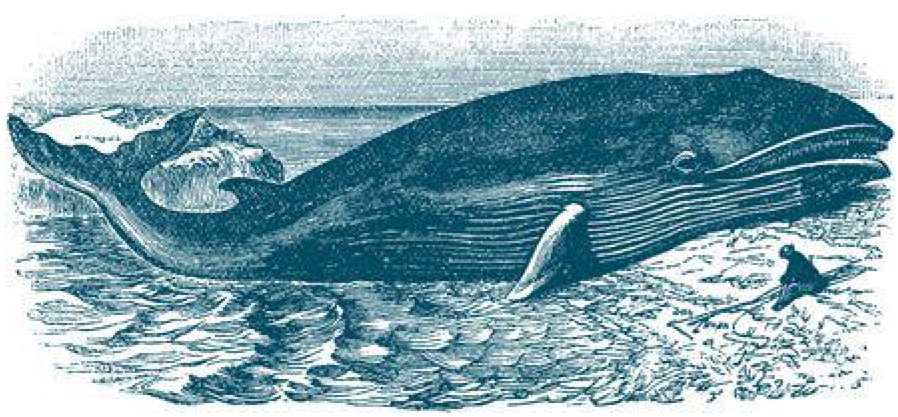
In 1783 Argand was closely involved with Montgolfier in his experiments to devise a hot air balloon, and an acquaintance began making copies of the Argand lamp, leading to extensive litigation. There were many problems to solve before the lamp could be manufactured in bulk. The design manufacture of the wick was solved by a lace-maker. The sourcing of heat-resistant glass to use next to the hot flame was another difficulty. Different types of oil were tested, and Argand experimented with methods to purify them, before deciding upon whale oil. Solder joints on the oil reservoir were found to leak, and a new solder was developed. Argand went into partnership with Matthew Boulton and William Parker in England to

manufacture the lamp, with demand outstripping supply. The whale oil lamp was rapidly displaced by the kerosene (paraffin) lamp after 1850, after kerosene was distilled from coal in 1846. Oil lamps are still used around the world, often kept as a reserve in case of an electricity shortage, and the Amish community still use them as they refrain from using electricity.

OIL LAMPS AND 'THE CITY THAT LIT THE WORLD'

AS THE world began using derivatives of Argand oil lamps, the whaling industry grew immensely, due to the insatiable demand for whale oil. Whale oil's principal use was in oil lamps and to make smokeless candles. It was the first animal or mineral oil to achieve commercial viability and also served as a dependable lubricant for the new machines powering the Industrial Revolution. Whale oil was also later used to make margarine and was the basis for an effective protective paint for steel, Rust-Oleum. The discovery of petroleum during drilling in the late 19th century led to petroleum-based waxes and oils that replaced whale oils in most non-food applications. Thankfully, the discovery and use of kerosene and petroleum ensured that whales were not hunted to extinction.

In the early 1800s, whaling ships from New England embarked on voyages to the Pacific Ocean in search of sperm whales. One town, New Bedford in Massachusetts, became known as the world centre of whaling. Of the more than 700 whaling ships on the world's oceans in the 1840s, more than 400 called New Bedford their home port. Whaling captains built large houses in the best neighbourhoods, and New Bedford was known as '*The City that Lit the World*'.



AGE OF THE EARTH

—— 1785 (*publication* 1788) ——

JAMES HUTTON 1726–1797, SCOTLAND

In the late 18th century it was generally believed that Earth had come into creation on 22 October 4004 BCE. This date arose because of the 17th-century analysis of the Bible by Archbishop James Ussher of Ireland. It was thought that fossils were the remains of animals that had perished during the Biblical flood, although Shen, Steno and Hooke had realized their true nature. As for the structure of the Earth, scientists agreed that much of its bedrock consisted of long, parallel layers which occurred at various angles, and that sediments deposited by the waters of the Great Flood had been compressed to form stone. However, Hutton perceived that this sedimentation takes place so slowly that even the oldest rocks are made up of, in his words, '*materials furnished from the ruins of former continents*'. The reverse process occurs when rock exposed to the atmosphere erodes and decays. He called this coupling of destruction and renewal the '*great geological cycle*', and realized that it had been completed innumerable times. This Scottish farmer had observed the rocks around his farm, and came to reason that the Earth was perpetually being formed and reformed. He understood that, for example, molten material is forced up into mountains, eroded and then the eroded sediments are washed away. Hutton was the first to recognize that the history of the Earth could be determined by understanding how processes such as erosion and sedimentation work in the present day. His ideas and approach established geology as a formal science.

Hutton studied medicine and chemistry at the universities of Edinburgh, Paris and Leiden (in the Netherlands), but then spent 14 years running two small family farms. Farming gave rise to Hutton's obsession with how the land was affected by the destructive forces of wind and weather. He began to devote his scientific knowledge and his powers of observation to 'geology', a subject that had only recently acquired a name. In 1768 he moved to Edinburgh, where a visitor a few years later described his study as '*so full of fossils and chemical apparatus that there is hardly room to sit down*'. In a 1785 paper, *Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land*

upon the Globe presented to the Royal Society of Edinburgh, Hutton described his version of the Earth's continuing transition. Relying on observations and experiments carried out over 25 years, he described a continuous cycle in which rocks and soil are washed into the sea, compacted into bedrock, forced up to the surface by volcanic processes, and eventually worn away into sediment once again. Hutton concluded '*The result, therefore, of this physical enquiry is that we find no vestige of a beginning, no prospect of an end*.'

Hutton used as evidence a cliff at nearby Siccar Point, a rocky promontory in the county of Berwickshire on the east coast of Scotland. There was a juxtaposition of vertical layers of grey shale and overlying horizontal layers of red sandstone. This could only be explained by the action of massive forces over vast periods of time. Hutton informed his audience that the sediments now represented by the grey shale had, after deposition, been uplifted, tilted, eroded away, and then covered by an ocean, from which the red sandstone was then deposited. The boundary between the two rock types at Siccar Point is now called the *Hutton Unconformity*. The fundamental force of change had to be subterranean heat, evidenced by the existence of hot springs and volcanoes. From his detailed observations of rock formations across Britain, Hutton inferred that high pressures and temperatures deep within the Earth would cause the chemical reactions that created formations of basalt, granite and mineral veins. He also proposed that internal heat causes the crust to warm up and expand, resulting in the upheavals that form mountains. The same process causes rock stratifications to tilt, fold and deform, as shown in the Siccar Point rocks.

Another of Hutton's major concepts was the *Theory of Uniformitarianism*. Geological forces at work in the present day, barely noticeable to the human eye, yet immense in their impact, are the same as those that operated in the past. This means that the rates at which processes such as erosion or sedimentation occur today are similar to past rates, making it possible to estimate the times it took to deposit a sandstone layer, for example, of a given thickness. It became evident from such analysis that enormous lengths of time were required to account for the thicknesses of exposed rock layers. *Uniformitarianism* is thus one of the fundamental principles of *earth science*. Hutton's theories amounted to a frontal attack on a popular contemporary school of thought called *catastrophism*, the belief that only natural catastrophes, such as the Great Flood, could account for the form and nature of a 6000-yearold Earth. The great age of Earth was the first revolutionary concept to emerge from the new science of geology. Hutton's work affected all sciences, but not until Sir Charles Lyell's *Principles of Geology* (1830–3) was there wide acceptance for his theory of uniformitarianism, three decades after Hutton's death.

HUTTON AND DARWINISM

HUTTON EVEN applied his theory of uniformitarianism to animal life, proposing a process of evolution and natural selection more than seven decades before the work of Darwin and Wallace. 'The founder of modern geology' directly influenced Darwin, who used Hutton's findings to account for the aeons of biological evolution in *On the Origin of the Species* in 1859.

HUTTON – DEEP TIME

DEEP TIME is Hutton's concept that the geologic timescale is vast because the Earth is very old. In 1981 John McPhee used the following metaphor to explain deep time in his book *Basin and Range*: '*Consider the Earth's history as the old measure of the English yard, the distance from the King's nose to the tip of his outstretched hand. One stroke of a nail file on his middle finger erases human history*.'

POWER LOOM

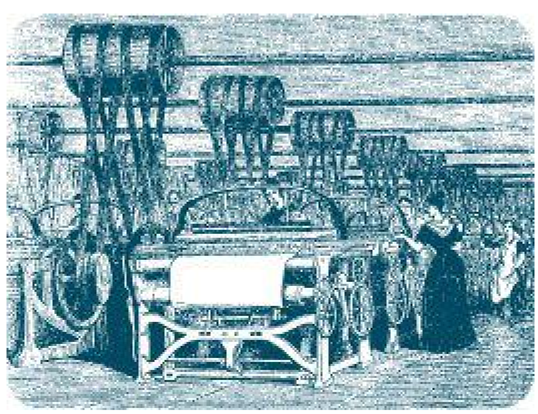
—— 1785 (*patented* 1787) ——

EDMUND CARTWRIGHT 1743–1823, ENGLAND

A rector and cathedral prebendary, Cartwright visited Richard Arkwright's cotton-spinning mills at Cromford in Derbyshire in 1784. He was inspired to construct a similar machine to improve the speed and quality of weaving. Cartwright said: '*Happening to be at Matlock in the summer of 1784, I fell in company with some gentlemen of Manchester, when the conversation turned on Arkwright's spinning machinery. One of the company observed that as soon as Arkwright's patent expired, so many mills would be erected and so much cotton spun that hands would never be found to weave it. To this I replied that Arkwright must then set his wits to work to invent a weaving mill. But it was not till the year 1787 that I completed my invention, when I took out my last weaving patent, August 1st of that year*.' It was thought that such a complicated procedure would be impossible to automate, but Cartwright had been inspired by seeing an automaton playing chess, which he thought a far more difficult invention.

He employed a carpenter and a blacksmith, patenting what he called the *power loom* in 1785. It was crude and inefficient, but improvements were made in subsequent versions. His second attempt at loom-building was far better.

Having taken out a new patent in 1787, in the same year Cartwright built a weaving shed in Doncaster. A bull was used for powering the looms, until a Boulton and Watt steam engine was installed two years later. Of the shed's 20 looms, 18 wove cotton, and by 1790 Cartwright's prospects were excellent. He sold a licence to Robert Grimshaw to build 500 of the new looms in a weaving shed at Knott Mill in Manchester. However, the building was burned to the ground in 1792, almost certainly by handloom weavers who were concerned about the threat to their livelihoods. Hundreds of spinning mules were also lost. Handloom weavers across the textile-producing areas feared the impact that power looms would have on their jobs. All operations that had been previously been done by the weaver's hands and feet could now be performed mechanically. The main task of the weavers employed by Cartwright was just to repair broken threads on the machine.



Grimshaw had only installed 24 power looms before the fire, and in the light of earlier, anonymous threats he declined to rebuild his mill. A scheme for a second factory with Cartwright's looms in nearby Gorton was shelved, and the arson influenced other manufacturers not to buy Cartwright's machines. No further orders were forthcoming for Cartwright's power looms. Meanwhile, Cartwright's Doncaster undertaking was beset by financial and technical problems. He was finally forced to close the mill in 1793 and declare himself bankrupt. His siblings rallied round and agreed to sell the family estate at Marnham to pay off the debts. Disillusioned, Cartwright turned his back on cotton weaving and also largely abandoned hopes for another promising invention, a wool-combing machine patented in 1790 that would have done the job of 20 workers. It had met with similar opposition. In 1797 he patented a steam engine that used alcohol instead of water to generate power, and also invented a rope-making machine or cordelier.

'LABRADOR' CARTWRIGHT

CARTWRIGHT'S brother John (1740–1824) was one of Britain's best-known radical politicians, nicknamed 'the father of Reform' because of his campaigning for parliamentary reform. George, his eldest brother (1739–1819), followed his army career by becoming a fur trapper and explorer in Canada. George Cartwright earned the nickname of *Labrador Cartwright*, and was the first man to bring Inuit to Britain. A family of five accompanied him back after one voyage and became favourites at court, but four died of smallpox on their return voyage to Newfoundland.

The indebted Cartwright moved to London, working on other inventions such as interlocking bricks and incombustible floorboards. None proved workable. He had high expectations for another steam engine with a novel mechanism that translated the piston's up-and-down movement into a rotational motion. It also had sprung steel piston rings, replacing the string and leather that had been used since before Watt's time. However, his lack of business acumen and backing meant that the project failed, although Robert Fulton showed interest. By the early part of the 19th century a large number of factory owners were using a modified version of Cartwright's power loom. When Cartwright discovered what was happening, he applied

to the House of Commons for compensation, and in 1809 he was voted £10,000 in recognition of the national benefits of his power loom. Automation had transformed textile production.

MODERN SOAP

—— 1789 ——

ANDREW PEARS 1766–1845, ENGLAND

Although soap was invented in Mesopotamia around 2800 BCE, credit is here being given to the first recognizably ‘modern’ soap. The ancient Mesopotamians somehow worked out that mixing animal fat with wood ash makes a substance that can clean clothes and people. A formula for soap consisting of water, alkali and cassia oil was written on a Babylonian clay tablet around 2200 BCE. The Ebers Papyrus of 1550 BCE tells us that the Egyptians bathed regularly, and combined animal and vegetable oils with alkaline salts to create a soap-like substance. The Romans built public baths all over their empire, but did not use soap. They cleaned themselves by oiling their bodies, then scraping off the oil using a special scraper called a *strigil*. Rich Romans would employ a slave to scrape them clean.

THE FIRST WHITE SOAP

HENRY DAVIS POCHIN (1824–1895) made a fortune by inventing a process for the clarification of rosin, a brown substance used to make soap. He passed steam through it, so after distillation it came out as white soap, enabling the production of fancy white soaps, which could also then be dyed to produce coloured soaps.

People were making soap in Europe from the 600s, but personal hygiene was not of real importance. Soap was costly and it remained a luxury item through the ages until the middle of the 19th century. It was made by boiling tallow (animal fat) or vegetable oils with alkali containing wood ash. Methods of soap-making improved with two scientific discoveries. In 1790 the French chemist Nicolas Leblanc (1742–1806) invented a process for creating sodium hydroxide (caustic soda) from sodium chloride (common table salt). This made cheap soap manufacture possible by enabling chemists to develop a procedure whereby natural fats and oils

could react with caustic soda. The method was further refined when the French chemist Michel Eugène Chevreul (1786–1889) discovered the nature of fats and oils in 1823. As soap production became less expensive and attitudes towards personal cleanliness changed, soap-making became an important industry.

Until the Industrial Revolution, soap-making was a small-scale business, and the resulting product was uneven and gritty. Andrew Pears opened a barber's shop in the then fashionable residential area of Soho, London, and attracted the custom of wealthy families. He knew that the London upper classes cultivated a delicate white complexion, while a tanned face was associated with the working class who toiled in the open air. Andrew Pears attempted to develop a gentle soap, and found a way of removing the impurities and refining the base soap, before adding the perfume. He began making a high-quality, transparent soap in 1789, which had longer-lasting bubbles. Its transparency was the unique selling proposition that established the image of Pears soap. His method of mellowing, and ageing for over two months, each long-lasting Pears soap bar is still used today. Natural oils and pure glycerine are combined with the fragrances of rosemary, cedar and thyme. Now it smells more like coal tar, unfortunately, after a recent alteration in its composition. Pears Soap was the world's first registered brand, and is therefore the world's oldest continuously existing brand. The actress Lillie Langtry's famous ivory complexion made her money as the first woman to endorse a commercial product, advertising Pears Soap.

SOAP STORIES AND B.O.

A SOAP-MAKER at Procter & Gamble went to lunch one day in 1879, but forgot to turn off the soap mixer. More than the usual amount of air was whipped into the batch of pure white soap that the company sold under the name *The White Soap*. Fearing the sack, the soap-maker kept quiet, and the airfilled soap was packaged and shipped to customers around the USA. Customers were soon asking for more '*soap that floats*'. Company officials discovered what had happened, and turned it into one of P&G's most successful products, *Ivory Soap*. Lever Brothers created *Lifebuoy* soap in 1895, selling it as an antiseptic soap, and later changing the name to *Lifebuoy Health Soap*. The company first coined the term '*B.O.*' for body odour as part of their marketing campaign. William Colgate started a candle and soap making company in New York City in 1806. By 1906, his company was making over 3000 different soaps, perfumes and other products such as *Colgate Dental Cream* (1877).

In 1864, Caleb Johnson founded a soap company called B.J. Johnson Soap Co, in Milwaukee. In 1898, the company introduced a soap made from a mixture of palm and olive oils, called *Palmolive*. It was so successful that that the B.J. Johnson Soap Co changed its name to Palmolive in 1917, and later became part of Colgate-Palmolive.

COTTON GIN

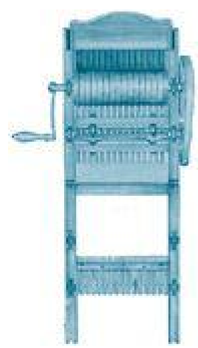
—— 1793 (*patented* 1794) ——

ELI WHITNEY 1765–1825, NEW HAVEN, CONNECTICUT

Eli Whitney's invention of the *cotton gin* (short for cotton engine) revolutionized the cotton industry, enabling economic mass production in the United States. Farming cotton required hundreds of man-hours to clean and separate cotton seeds from the raw cotton fibres. Simple seed-removing devices had been around for centuries, but Eli Whitney automated the seed separation process. The 'gin' was a wooden cylinder surrounded by rows of slender spikes ('teeth') which pulled the lint through the bars of a comb-like grid. The grids were closely spaced, preventing the seeds from passing through. The 'teeth' combed out the cotton and separated the seeds, and brushes continuously removed the loose cotton lint to prevent machine jams. Whitney said that he was thinking of an improved method of seeding

cotton, and was inspired by seeing a cat attempting to pull a chicken through a fence, only being able to pull through some of the feathers.

Whitney’s machine could generate up to 50 pounds (23 kg) of cleaned cotton daily, making cotton production much more profitable for the southern states. The fibres were processed into cotton goods, and the removed seeds could be used to grow more cotton or to produce cottonseed oil. The gins later became horse-drawn and water-powered. Cotton production increased, and costs were lowered. Cotton soon became the number one selling textile, accounting for over half of the USA’s exports, with the southern states providing two-thirds of the world’s cotton. Exports rose from around 470,000 pounds (213,200 kg) in 1793 to 3.2 million pounds (1.45 million kg) in 1810. The yield of raw cotton doubled each decade after 1800, demand being fed by other inventions of the Industrial Revolution, such as the machines to spin and weave it and the steamboat to transport it.



THE COTTON GIN AND THE CIVIL WAR

WHILE THE cotton gin reduced the labour of removing seeds, it did not reduce the need for slaves to grow and pick the cotton. Slaveholders such as George Washington had been giving away their slaves, as growing rice, cotton and tobacco had become unprofitable, but suddenly they were valuable again. Growing cotton became so profitable for planters that it greatly increased their demand for both land and slave labour. In 1790 there were just six slave states, but by 1860 there were 15. The number of slaves rose from around 700,000 before Eli Whitney’s patent to around 3.2 million in 1850. The growth of ‘*King Cotton*’ made the South wealthy, based upon slavery, and was one of the principal causes of the American Civil War.

PENCIL

—— 1795 ——

NICOLAS-JACQUES CONTÉ 1755–1805, FRANCE

The development of the alphabet, writing and reading are possibly the most important landmarks in human history. However, it was only the appearance of easy-to-use writing implements such as the pen and pencil that made mass education and literacy possible. Pencils allowed everyone to write easily and cheaply. The origins of the pencil date to the ancient Egyptians and Romans, who used to write with a *stylus*. This was a thin, short metal stick, often made of lead, which was used to scratch words onto waxcovered papyrus. Pens were fashioned from the quills of feathers, and used by monks to write manuscripts. The quill pen was still being used into the 20th century. In 1564 a huge cache of graphite was discovered in Borrowdale, Cumbria, England. This remains the only large-scale deposit of pure graphite ever found in this solid form. Local residents used it to mark sheep, and soon discovered that they could cut the graphite into sticks and carry it with them. Because graphite easily breaks, users in Italy began hollowing out a stick of juniper wood and filling it with graphite to protect the mineral. Later versions sandwiched the graphite between two pencil halves and glued them together, the method still used today. The wooden sleeve prevents the core from breaking, and also from marking the user's hand during use. In 1662 the first mass-produced pencils were made in Nuremberg, Germany, using powdered graphite, sulphur and antimony.

WHY ARE THEY CALLED 'LEAD' PENCILS?

WHEN THE Borrowdale cache of graphite was discovered in 1564, scientists thought that graphite was a form of lead. This is why we still say ‘lead’ pencils. In German, the word for pencil is *bleistift*, literally lead pen. The word pencil comes from the Latin *pencillus*, which means little tail.

Conté was a French army officer, balloonist and painter, and he was asked by the French political leader Lazare Carnot to develop a pencil that did not rely on foreign imports. Britain, the only supplier in the world of the pure graphite sticks needed for pencils, was blockading the French Republic, and France was also unable to import the inferior German graphite pencil substitute. Conté discovered how to reconstitute graphite powder from other mines, and mixed this powdered graphite with clay. The mixture was formed into rods that were then fired in a kiln. He then pressed the rods between two half-cylinders of wood. He received a patent in 1795, forming a company which still makes pencils. He also invented the conté crayon, a hard pastel stick used by artists. In 1770, the English engineer Edward Naime created and began selling the first rubber erasers.

‘I WILL TAKE UP MY PENCIL’

IN 1880, at the age of 26, Vincent van Gogh suffered his first nervous breakdown. After a period of desperate wandering, he wrote to his brother Theo, his sole supporter: ‘*In spite of everything I shall rise again: I will take up my pencil, which I have forsaken in my great discouragement, and I will go on with my drawing*.’ In his remaining ten years of life, he discovered Impressionism in Paris and moved to the south of France, where he evolved his unique style. Van Gogh only used Faber pencils, as they were: ‘*superior to Carpenter’s pencils, a capital black and most agreeable*’.

The practice of painting pencils yellow began in the 1890s. Pencil manufacturers wanted to advertise that they were using high-quality Chinese graphite, so they painted them a colour associated with Chinese royalty. Today, 75 per cent of the pencils sold in the United States are still painted yellow. By the end of the 19th century more than 240,000 pencils were used each day in the United States alone. The favoured timber was red cedar, as it was aromatic and did not splinter when sharpened. Pencils create marks via physical abrasion, leaving behind a trail of solid core

material that adheres to a sheet of paper or other surface. By varying the ratio of graphite to clay, the hardness of the graphite rod can also be varied. Derwent produces twenty grades from 9H (very hard) to 9B (brittle, very soft) for its graphic pencils. Over 14 billion pencils are manufactured worldwide annually.

VACCINATION

—— 1796 ——

EDWARD JENNER 1749–1823, BERKELEY, ENGLAND

Jenner pioneered smallpox vaccination, thereby saving millions of lives, and he is popularly known as ‘the father of immunology’. A simple village doctor in Berkeley, Gloucestershire, Jenner treated a milkmaid named Sarah Nelmes for pus-filled blisters on her hands and arms caused by cowpox. He took pus from her pustules, and inserted it into small incisions on the arm of the eight-year-old James Phipps. Phipps developed cowpox, proving that the disease was transmittable between people. Jenner was testing his theory, drawn from local folklore, that milkmaids who suffered the mild disease of cowpox never contracted smallpox. Smallpox was one of the greatest killers of the period, especially among children. Jenner then injected Phipps with a controlled dose of smallpox – he became ill but did not contract the full disease. Jenner had proved that the inoculation of cowpox made Phipps immune to smallpox. He described his feelings in these words: ‘*The joy I felt as the prospect before me of being the instrument destined to take away from the world one of its greatest calamities was so excessive that I found myself in a kind of reverie*.’

He submitted a paper to the Royal Society in 1797 describing his experiment, but was told that he needed more proof. Jenner experimented on several other children, including his own 11-month-old son. In 1798 the results were finally published and accepted, with Jenner coining the word ‘vaccine’ from the Latin *vacca* (cow). The clergy hated the idea of using material from a diseased animal, while the public controversy stirred up by the treatment was satirized in an 1802 cartoon by James Gillray that showed

vaccinated patients sprouting cows' heads from various parts of their bodies. However, in 1854 an act of parliament made vaccination with cowpox compulsory, and deaths from smallpox fell dramatically. In 1979, the World Health Organization called smallpox an *eradicated disease*.

THE ERADICATION OF A VIRUS

IN THE early 1950s, 150 years after the introduction of vaccination, an estimated 50 million cases of smallpox still occurred in the world each year. This figure fell to around 10–15 million by 1967 because of vaccination. In 1967, the WHO launched an intensified plan to eradicate smallpox, which threatened 60 per cent of the world's population, killed every fourth victim, scarred or blinded most survivors, and eluded any form of treatment. Through the success of the global eradication campaign, smallpox was finally pushed back to the Horn of Africa and then to a single last natural case, which occurred in Somalia in 1977. Researchers debate whether or not to kill the last remaining samples of the virus, or to preserve it in case there may be some future reason to study it. There remains a concern that the smallpox virus could be intentionally spread through a terrorism attack, borne on the wind by aersosols.

MEANING OF FOSSILS

—– 1796 —–

WILLIAM SMITH 1769–1839, ENGLAND AND BARON GEORGES CUVIER 1769–1832, FRANCE

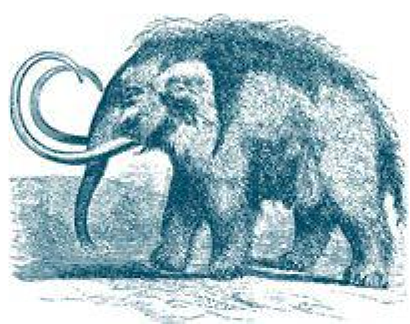
The two men independently established from geological evidence that evolution has occurred over time. Smith was a surveyor on a site where a canal was being dug in Somerset, and he made observations about the fossils found during excavations. People generally thought that fossils looked like living things, but with no actual connection with anything that had ever lived. Smith wrote in one of his notebooks in 1796: '*Fossils have been long studied as great curiosities, collected with great pains, treasured with great care and at a great expense, and shown and admired with as much pleasure as a child's hobby-horse is shown and admired by himself and his playfellows, because it is pretty; and this has been done by thousands who have never paid the least regard to that wonderful order and regularity with which nature has disposed of these singular productions, and assigned to each class its peculiar stratum*.' He documented that certain characteristic fossils are associated with particular geological strata, and that strata overlie each other in the same order in different geographic locations. He wrote: '…*each stratum contained organized fossils peculiar to itself, and might, in cases otherwise doubtful, be recognized and discriminated from others like it, but in a different part of the series, by examination of them*.'

Smith referred to the fact that fossil assemblages succeed each other vertically in the same order in different, often widely separated locales, as the principle of *faunal succession*, a rule now recognized as basic to the determination of the relative ages of rocks, strata and fossils. The fact that this principle held true also raised the question of why and how there been this succession of organisms that had changed over time. Thus Smith's work, together with that of Cuvier, prompted the first discussions of evolutionary theory. Smith travelled constantly across the face of Britain collecting mineral samples and fossils, and eventually prepared the first geological map of the island, published in 1815. For a time, he succeeded in making a living selling his maps, but his prices were undercut by copyists. Smith was forced into bankruptcy and was sent to a prison for debtors in London, his house and property being seized. After his release in 1819, he was able to continue his work as a surveyor, but his seminal insights into the history of life on Earth for some time went unrecognized for many years. However, in 1831 the Geological Society of London awarded him the first Wollaston Medal, its highest honour, the society's president calling William Smith the 'father of English geology'.

Cuvier was a French child prodigy, becoming a naturalist and zoologist, and the founder of the fields of vertebrate palaeontology and comparative anatomy. Ernst Mayr wrote in 1982 that Cuvier's '*contributions to science are almost too extensive to be listed…*' By showing in 1796 that the remains of huge animals such as woolly mammoths and giant ground sloths were distinct from those of any living animal, Cuvier established extinction as a fact. At the time, it was still generally believed that no animal had ever gone extinct. His *Le Règne Animal* was the earliest taxonomic classification to include descriptions of fossil forms, many of which he himself had

discovered, alongside those of living organisms. No other researcher in the pre-Darwinian period produced more new evidence demonstrating that evolution actually does occur. His *Récherches sur les Ossemens fossiles des Quadrupèdes* (1812) provided irrefutable proof of the occurrence of evolution. Cuvier had found that the lower the stratum, the more distinct was its fauna from that of the present (i.e. the lower the percentage of modern forms and the higher that of extinct ones). Cuvier documented the fact of evolution that theorists would later try to explain, and popularized the idea that fossils tell the story of past life on Earth.

His 1811 study of the geology of the Paris basin showed that particular fossils were characteristic of certain strata, and that the same strata occurred in the same order, one above the other, in different geographic locations. Like Smith, Cuvier concluded that they must have been laid down over a very long period of time and that there had clearly been a faunal succession with the passage of the ages. He also provided conclusive proof that the basin had been periodically submerged beneath the sea. His work, together with that of Smith and Hutton, established the science of *stratigraphy*, a major step in the progress of palaeontology, geology and evolutionary thought.



ORIGIN AND STABILITY OF THE SOLAR SYSTEM

— 1796 —

PIERRE-SIMON LAPLACE 1749–1827, FRANCE

Laplace was the first to explain how the solar system was formed and why it had stabilized, and he even conceptualized the existence of *black holes*. The scientific discoveries of this mathematician, physicist and astronomer, ‘the Newton of France’, were made between the twentieth and fortieth years of his life. The succeeding 37 years were spent in composing

his *Exposition du Système du Monde* ('The System of the World') (1796) and *Méchanique Céleste* ('The Mechanics of the Heavens') (1799–1825). In celestial mechanics Laplace discovered the invariability of the planetary mean motions, and the consequent stability of the solar system. *The Mechanics of the Heavens* was important because it translated the geometrical study of mechanics used by Newton to one based on calculus, then known as physical mechanics.

NAPOLEON, LAPLACE AND THE GOD HYPOTHESIS

LAPLACE HAD an appointment to ask Napoleon to accept a copy of his *The Mechanics of the Heavens*, but someone had told Napoleon that the book contained no mention of the name of God. Napoleon asked '*M. Laplace, they tell me you have written this large book on the system of the universe, and have never even mentioned its Creator… Mais où est Dieu dans tout cela?*' ('But where is God in all this?)'. Laplace answered bluntly, '*Je n'avais pas besoin de cette hypothèse-là.*' ('I had no need of that hypothesis'). Napoleon, greatly amused, answered, '*Ah! c'est une belle hypothèse; ça explique beaucoup de choses.*' ('Ah, that is a beautiful hypothesis; that explains many things.')

Laplace proved the dynamical stability of the solar system (with tidal friction ignored) on short time-scales. On long time-scales, this assertion was only disproved in the early 1990s. Laplace worked out the reason for the *libration of the Moon* (its oscillations in longitude and latitude). According to his hypothesis the solar system had evolved from a globular mass of incandescent gas, rotating around an axis through its centre of mass. As it cooled, this mass contracted and successive rings broke off from its outer edge. These rings in their turn cooled, and finally condensed into the planets, while the Sun represented the central core which is still left. He invented gravitational potential and showed it obeyed *Laplace's equation* in empty space. He calculated how large the Sun would have to be for all its light to be eventually pulled back by gravity, creating a *black hole* from which light could not escape, but the calculation was dropped from later editions as the concept of back holes was not then understood. Laplace also systematized and elaborated probability theory in his *Théorie analytique des probabilités* ('Philosophical Essay on Probability') of 1814. Modern

mathematical analysis owes mainly to Laplace the full development of the co-efficients, of the potential and the theory of probabilities. Laplace died in 1827 at the age of 77. His last words were reportedly: '*Ce que nous connaissons est peu de chose, ce que nous ignorons est immense.*' ('What we know is not much. What we are ignorant of, is immense.')

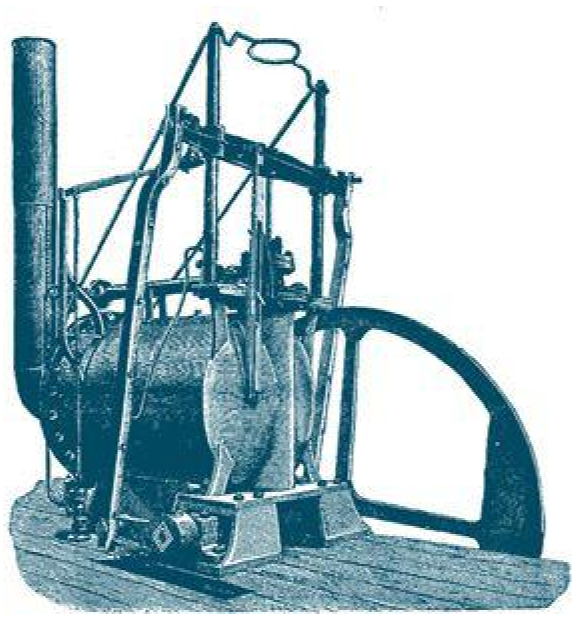
HIGH–PRESSURE STEAM ENGINE

–– 1797 (*patented* 1802) ––

RICHARD TREVITHICK 1771–1833, CORNWALL, ENGLAND

Trevithick is an unsung hero of the Industrial Revolution who used his pioneering engine design to power a steam car (1801), the world's first railway locomotive (1804), a steam dredger (1806) and a steam threshing machine (1812). Not content with these incredible breakthoughs, he made the earliest fire tube boiler in 1812 and a screw propeller in 1815. The 'father of railways', Trevithick's railway engines were running a quarter of a century before George Stephenson's, and his steam engines enabled huge improvements in industrial efficiency and effectiveness. The son of a Cornish mine captain, Trevithick picked up engineering knowledge by wandering around the mines where his father worked. He learned so quickly that, by the age of 19, he was being employed as a consulting engineer. Trevithick searched for a way to by-pass the steam engine and separate condenser patents of James Watt, which were hugely expensive to

Cornish tin mine owners. In 1797 Trevithick made his first models of high-pressure engines. In these new engines the steam from the cylinders was expelled to the atmosphere, doing away with the need for a separate condenser, thus circumventing Watt’s patents. The design also produced much more power. Trevithick called his high-pressure steam engines *puffing devils* or *puffers*, because of the noise they made, and the name carried on as slang for railway steam locomotives in later years.



Around 1800, the year when Watt’s patents expired, Trevithick was ready to launch his powerful engines, which could now be made small enough for transport applications. Technological developments and improvements in manufacturing techniques (partly brought about by the adoption of the steam engine as a power source) resulted in the design of more efficient engines. These could now be smaller, faster or more powerful, depending on the intended application. Steam engines remained the dominant source of power well into the 20th century, when advances in the design of electric motors and internal combustion engines gradually resulted in the vast majority of reciprocating steam engines being replaced in commercial usage. Steam turbines replaced them in power generation. Trevithick built his first road steam carriage at Camborne in 1801, and another road machine followed in 1803 which ran several times in London. The following year, he patented the high-pressure steam engine for stationary and locomotive use. In 1803 he made a second steam carriage and

demonstrated it on the streets of London. Trevithick's *London Road Locomotive* ran between Leather Street and Paddington, via Oxford Street. This was the first powered vehicle to use roads, in effect the first car. However, roads across Britain were not suitable for steam transport, Trevithick lost money on this venture and let this work lapse, concentrating upon making improvements to his steam engine.

Richard Trevithick built the first railway locomotive, not George Stephenson. Sources relate that it was Trevithick's Penydarren engine of 1804, but in 1802–3 he had made one for the Coalbrookdale Company in Shropshire, the first firm to take an interest in his high-pressure engine after the patent of 1802. It is not known, however, whether this engine actually ran. He next interested Samuel Homfray of Penydarren Ironworks in his engines, and Trevithick built several stationary ones. His first locomotive ran on the normally horse-drawn line at Penydarren ironworks in South Wales in 1804, pulling 10 tons (10,160 kg) of iron and 70 men. Unfortunately for Trevithick, the cast-iron rails of the tramways were not strong enough to support the weight of his steam locomotive, as its weight broke many plates and couplings. Later wrought-iron (rolled steel) rails would have allowed the great weight to be accommodated. Stephenson's *Rocket* was built 25 years later, with the benefit of wrought-iron rails. Trevithick, however, had first proved that steam power would haul useful loads on rails by simple adhesion. Trevithick's engine was used several times more. On 4 March Trevithick said that he had tried it with 25 tons (25,400 kg) of iron, for which it was more than a match. In April the engine was being used for pumping water. A letter by Homfray says that the boiler was cast iron, 6 feet (1.82 m) long and 4 feet 3 inches (1.3 m) diameter, that the cylinder was 8 inches (20.3 cm) in diameter, raising water a height of 28 feet (8.5 m) by a pump 18¼ inches (46.4 cm) in diameter and with a stroke of 4 feet 6 inches (1.37 m), at 18 strokes a minute. Before early July it hauled at least two more trains, but thereafter it seems to have run no more on rails, being used for winding or driving a hammer at pits.

FROM CRADLE TO GRAVE

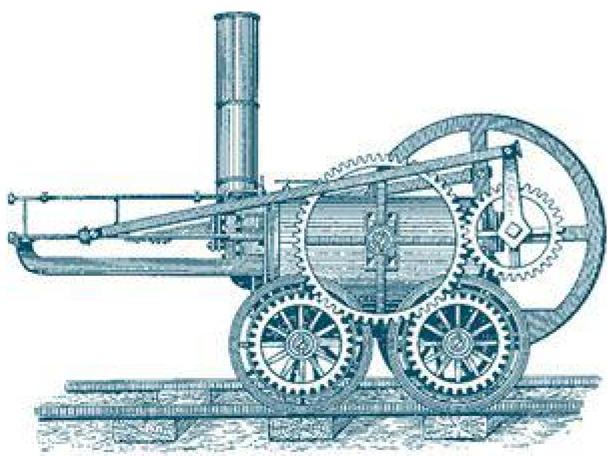
A SCHOOL report says that Trevithick was '*a disobedient, slow, obstinate, spoiled boy, frequently absent and very inattentive*'. In 1833, aged 62, he was taken ill while working for John Hall Engineering in Dartford, Kent.

Trevithick would have been buried in a pauper's grave but a collection was made by the mechanics at Hall's works to pay for the funeral. A few months earlier, he had written his own epitaph in a letter to Davies Gilbert: '*I have been branded with folly and madness for attempting what the world calls impossibilities, and even from the great engineer, the late Mr. James Watt, who said to an eminent scientific character still living, that I deserved hanging for bringing into use the high-pressure engine. This so far has been my reward from the public; but should this be all, I shall be satisfied by the great secret pleasure and laudable pride that I feel in my own breast from having been the instrument of bringing forward and maturing new principles and new arrangements of boundless value to my country. However much I may be straitened in pecuniary circumstances, the great honour of being a useful subject can never be taken from me, which to me far exceeds riches.*'

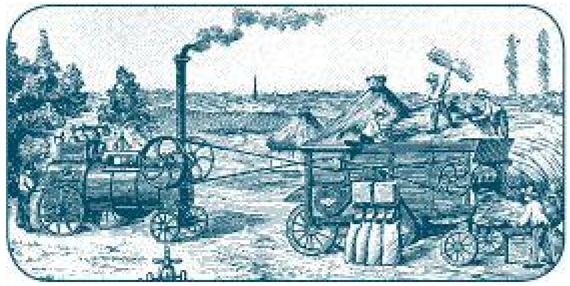
George Stephenson and Trevithick met at this time, and Trevithick played with Stephenson's young son Robert, leading to a curious coincidence later in his life (described below). An engine similar to the Penydarren example was built to Trevithick's specifications at Newcastle in 1805. This *Wylam locomotive* was built at Newcastle-upon-Tyne to drive a paddle-wheel barge. It seems highly likely that George Stephenson of Newcastle saw this machine, and it obviously influenced the man whose name was to become synonymous with the Railway Era. Trevithick's restless nature turned to using steam for dredging and tunnelling. In 1806 he built the first steam dredger, for use on the River Thames. This worked reasonably well, but cost more to run than paying manual labourers to do the same job. Trevithick then became involved in building a Thames tunnel at Limehouse. He used steam engines to ventilate the workings and pump out water, but the venture failed after several years' work. Meanwhile, new ideas poured from Trevithick. By 1808, he was giving rides at 1 shilling a time on a circular railway that he had constructed at Euston, London. It was advertised as '*Trevithick's Catch-Me-Who-Can*' and the '*Circle Line*'. In 1809, Trevithick patented floating docks, iron ships, iron masts, iron buoys and steam engines for ships, and in 1810 took out patents for steam propulsion of sea vessels.

In 1811 Trevithick was declared bankrupt, but he still was able to install his first *Cornish Engine and boiler*. The successful high-pressure 'Cornish

boiler’ was the earliest form of fire-tube boiler. This was a long horizontal cylinder with a single large flue containing the fire. The fire itself was on an iron grating placed across this flue, with a shallow ash-pan beneath to collect the non-combustible residue. Although considered as low-pressure (perhaps 25 psi) today, the use of a cylindrical boiler shell permitted a higher pressure than the earlier *haystack* boilers, such as the Newcomen type. The Cornish boiler’s furnace relied on natural draught, and a tall chimney was needed at the far end of the flue to encourage a good supply of air to the fire. For efficiency, the new boiler was commonly encased beneath by a brick-built chamber. Flue gases were routed through this, outside the iron boiler shell, after passing through the fire-tube and so to a chimney that was now placed at the front face of the boiler. It was the earliest and simplest flued boiler, first installed at Dolcoath copper and tin mine near Camborne in 1812. These Cornish boilers had many advantages over preceding *wagon boilers* used in mines.



Trevithick next pioneered the use of high-pressure steam in agriculture. In 1812 he built a machine for threshing corn for Sir Christopher Hawkins of Trewithen in Cornwall. It was so successful that it continued to work until 1879, when it was presented to the Science Museum in London. Trevithick also designed a steam cultivator, although this was probably not built. His engines were also used to drive sugar mills in the West Indies. In 1812 he built a rock boring machine for the Plymouth Breakwater company. In 1815 Trevithick took out more patents for his high-pressure steam engine, the plunger pole steam engine, the Reaction turbine and the screw propeller.



In 1816, Trevithick sailed to Peru to sort out problems with nine engines he had sold to the silver mines at Cerro de Pasco in 1814. Falling out with the owners, he travelled the country advising other mines and was rewarded when the Peruvian government ceded him some mining rights. He worked in Costa Rica, Ecuador and Nicaragua, and had just begun to operate a copper and silver mine when he was forced to serve in Simon Bolivar's army. Trevithick designed and built a recoil gun carriage for the revolutionaries, before being released back to civilian life. However, the Spanish army had taken over the area around his mine, his machinery had been wrecked in the revolutionary war and Trevithick had to flee. After ten years in Peru, he trekked to Colombia, extremely ill and impoverished. In one of his letters home he reported being '*half drowned, half hanged, and the rest devoured by alligators*'. Here he fortunately met Robert, the son of George Stephenson, who gave Trevithick £50 for his passage back to Britain. Trevithick attempted to resume his engineering career, and a petition to parliament for a grant for his work in Cornish mines failed. He took out more patents: in 1827 on new methods for centring ordnance on pivots; 1828 on discharging ship's cargoes; 1829 on new improved steam engine; 1831 on boiler and condenser, and a portable stove; 1832 on super heater for locomotion, and jet propulsion of vessels. He also designed a 1000-foot- (330-m-) high iron column to commemorate the Reform Bill. Parliament passed a bill, but the column was never built. The genius who gave the world the high-pressure steam engine, the railway locomotive and the fire-tube boiler died penniless.

POPULATION GROWTH AND RESOURCES RELATIONSHIP

—— 1798 ——

THOMAS ROBERT MALTHUS 1766–1834, ENGLAND

This mathematician and statistician became the world’s first professor of political economy in 1805. His best known work, *An Essay on the Principle of Population*, was published in 1798. It was one of the first works to undertake a systematic account of human society. Malthus argued that increases in population would eventually disable the ability of the world to feed itself, as population would outgrow resources. He stated that populations expand in such a way as to overtake the cultivation of sufficient land for crops. A *Malthusian catastrophe* would be a forced return to subsistence-level conditions because population growth had outpaced agricultural production. The Agricultural Revolution, with its new techniques of farming and synthetic fertilizers, has delayed this outcome, but his ideas have also been applied to non-food shortages, for example energy supplies and clean water. Many scientists believe that increases in farming efficiency and alternative energy production make the Malthusian model invalid, but they neglect the fast-rising prosperity and consumption trends of China and India as their economies power ahead. World population is now over 7 billion people, of which 37 per cent live in those two countries. It is growing in real terms at over 1.2 per cent per year.

In 1798 Malthus determined that the human population as a whole has passed the numerical point at which all could live in comfort, and that we had entered a stage where many of the world’s citizens and future generations would be trapped in misery. Even today, children in developing countries are dying at the rate of approximately 11,000,000 per year from preventable diseases. Across the globe there are large areas which experience high infant mortality, malnutrition, low standards of sanitation, inadequate and/or polluted drinking water, widespread disease, local wars

and political unrest. Food production has peaked in some regions where food is needed the most. In South Asia, around half of the land has been so degraded that it no longer sustains food production. In China there has been a 27 per cent irreversible loss of land for agriculture, and it continues to lose arable land at the rate of 920 square miles (2400 sq km) per year. In Madagascar, 30 per cent of previously arable land is irreversibly barren.

THE CONSEQUENCES OF OVER-POPULATION

'*The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation. They are the precursors in the great army of destruction, and often finish the dreadful work themselves. But should they fail in this war of extermination, sickly seasons, epidemics, pestilence, and plague advance in terrific array, and sweep off their thousands and tens of thousands. Should success be still incomplete, gigantic inevitable famine stalks in the rear, and with one mighty blow levels the population with the food of the world.*' T.R Malthus, *An Essay on the Principle of Population*, 1798

THE WORLD POPULATION IN SONG

In 1939, at the outbreak of the Second World War, the world population was estimated at *c*.2.3 billion. Now it is heading towards 7.1 billion at an alarming speed. This author was born in 1946, and fondly remembers the satiric music of Tom Lehrer in the 1950s, with a favourite song being 'We Will All Go Together When We Go', about the effects of nuclear war. World population was then less than 3 billion and has almost trebled in my lifetime. This is one verse of the song:

'*And we will all bake together when we bake.*
There'll be nobody present at the wake.
With complete participation
In that grand incineration,
Nearly three billion hunks of well-done steak.'

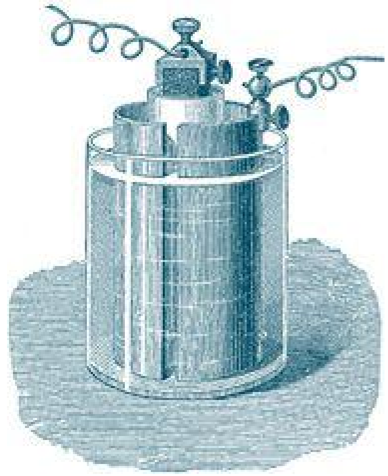
A further way of analyzing resource limitation highlights the dwindling area for storage of soil contaminants and water pollution. The high rate of increase of toxic chemicals in the environment (especially persistent organic chemicals and endocrine-altering chemicals) is creating a circumstance of resource limitation (e.g. safe potable water and safe arable land). The seas are acidifying because of the effects of over-population. Along with overfishing this is causing ocean species extinctions. Malthus's first law of sustainability is '*Population growth or growth in the rate of consumption of resources cannot be* [indefinitely] *sustained.*' Energy sources, such as petroleum, natural gas and coal are being depleted at an increasing rate – there is no potential for steady growth of a declining resource. At some stage politicians hopefully will become aware that the pressing problem for the world is not climate change, which has always happened and will always happen, but population growth. Malthus believed that population growth would lead to war, famine and fighting for scarce resources and his message is becoming more urgent as every day passes.

ELECTRIC BATTERY

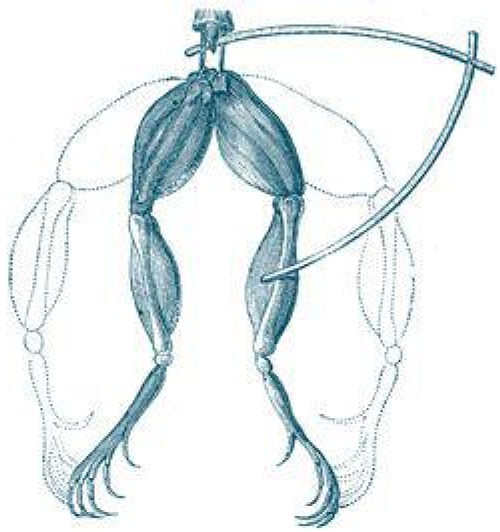
—— 1800 ——

ALESSANDRO VOLTA 1745–1827, ITALY

This physicist became professor of physics at the Royal School in Como in 1774, and in the following year he devised the *electrophorus*, a device that produced charges of static electricity. This capacitive generator uses the process of electrostatic induction to produce the electric charge. A version had been invented in 1762, but Volta improved and popularized the device. In 1776–7 he applied himself to chemistry, studying atmospheric electricity and devising experiments such as the ignition of gases by an electric spark in a closed vessel. The year 1777 saw Volta researching the chemistry of gases, and discovering methane.



Luigi Galvani had noted ‘animal electricity’ when two dissimilar metals were connected in series with a severed frog’s leg, and to one another. Volta realized that the frog’s leg served as both a conductor of electricity (an electrolyte) and as a detector of electricity. He replicated the experiment using brine-soaked paper instead of a frog’s leg. By 1800 he had developed the so-called *voltaic pile*, a forerunner of the electric battery, which was the first battery to produce a reliable, steady current of electricity. A battery is a device that stores energy and makes it available in an electrical form, by converting chemical energy into electric energy. It is so-called because it is a connected bunch (or *battery*) of electro-chemical devices. Volta’s battery is credited as being the first electrochemical cell, consisting of alternating discs, or electrodes, of copper and one of zinc. The electrolyte sandwiched between the metals could be cardboard soaked in sulphuric acid or a brine mixture of salt and water. Volta also sent an electric current along insulated wire a distance of 30 miles (48 km) from Como to Milan to set off a pistol. This was a forerunner of the telegraph, which also uses a current to send signals over long distance. He additionally made discoveries in pneumatics, electrostatics and meteorology. In honour of his work in the field of electricity, Napoleon made Volta a count in 1810, and in 1815 the emperor of Austria named him a professor of philosophy at Padua. His works were later published in five volumes in Florence, and in 1881 the electrical unit, the *volt*, was named after him. Batteries are a worldwide power source today, generating over $50 billion in annual sales.



CHLORINATION OF WATER

—— 1800 ——

WILLIAM CUMBERLAND CRUIKSHANK 1745–1800, SCOTLAND

Possibly more lives have been saved and more disease prevented by this contribution to sanitation and public hygiene than by any other single achievement in medicine and public health. The chemical element chlorine is essential to most forms of life, its most common compound being common salt (sodium chloride). In its dichlorine form it is a powerful oxidant, being used in bleaching and disinfectants. Around 1630 chlorine was recognized as a gas, and in 1774 it was first prepared and studied by Carl Wilhelm Scheele (1742–1786). Scheele observed several of its properties: the bleaching effect on litmus, the deadly effect on insects, the yellow-green colour and the distinctive smell. The anatomist and chemist William Cruikshank had been the first to cause crystals to be precipitated from urine by the use of nitric acid in 1797, and he identified carbon monoxide as a compound of carbon and oxygen in 1800. In the same year, he used chlorine to purify water. A year later, Guyton de Morveau in France recommended chlorine for disinfecting the air.

CHLORINE AS A WAR WEAPON

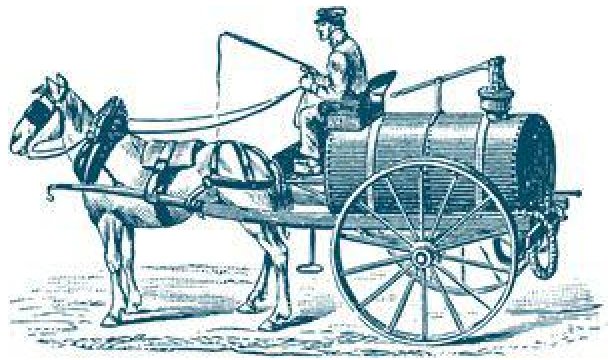
CHLORINE GAS was first introduced as a weapon at sunrise on 22 April 1915 by the German army at Ypres. A total of 5700 canisters containing

168 tons (170 tonnes) of chlorine gas were released. The results were disastrous, as gas masks had not been invented. French soldiers reported seeing yellow-green clouds, with a distinctive smell of pineapple and pepper, drifting slowly towards the Allied trenches. French officers assumed that the German infantry were advancing behind a smoke screen. Covering 4 miles (6.4 km) of trench lines, the gas affected 10,000 troops, half of whom died within ten minutes of the gas reaching the front line. Those who survived were temporarily blinded and stumbled around in confusion, coughing heavily. About 2000 of these troops were captured as prisoners-of-war. As the German soldiers were concerned about what the chlorine gas would do to them, they hesitated about moving forward in large numbers. Their delayed attack enabled British and Canadian troops to retake the position before the Germans burst through the 4-mile (6.4-km) gap that the chlorine gas had created. Chlorine gas destroys the respiratory organs of its victims, and this led to a slow death by asphyxiation. One nurse described the death of one soldier who had been in the trenches during a chlorine gas attack: '*He was sitting on the bed, fighting for breath, his lips plum coloured. He was a magnificent young Canadian past all hope in the asphyxia of chlorine. I shall never forget the look in his eyes as he turned to me and gasped: "I can't die! Is it possible that nothing can be done for me?*"' Doctors were unable to find a way of successfully treating chlorine gas poisoning. However, a disadvantage for the side that launched chlorine gas attacks was that it made the victim cough, and therefore limited his intake of the poison. Both sides found that phosgene was more effective as a killing agent than chlorine. Only a small amount was needed to make it impossible for the soldier to keep fighting, and it killed its victim within 48 hours of the attack.

Water used for drinking and cooking should be free of pathogenic (disease-causing) micro-organisms that cause such illnesses as typhoid fever, dysentery, cholera and gastroenteritis. Whether a person contracts these diseases from contaminated water depends on the type of pathogen, the number of organisms in the water (density), the strength of the organism (virulence), the volume of water ingested and the susceptibility of the individual. Purification of drinking water containing pathogenic micro-organisms requires a treatment called disinfection. Although several methods eliminate disease-causing micro-organisms in water, chlorination

is the most commonly used because of its lower cost. Chlorination is effective against many pathogenic bacteria, but at normal dosage rates it does not kill all viruses, cysts or worms. When combined with filtration, chlorination is an excellent way of disinfecting drinking water supplies. However, the chlorination of public drinking supplies was originally met with resistance, as people were concerned about potential health side-effects. Chlorination is also used to help sanitize the water in swimming pools and as a disinfection stage in sewage treatment.

The use of liquefied chlorine for the disinfection of water was first proposed by Lieutenant Nesfield of the Indian Medical Service: '*It occurred to me that chlorine gas might be found satisfactory…if suitable means could be found for using it…The next important question was how to render the gas portable. This might be accomplished in two ways: By liquefying it, and storing it in lead-lined iron vessels, having a jet with a very fine capillary canal, and fitted with a tap or a screw cap The tap is turned on, and the cylinder placed in the amount of water required. The chlorine bubbles out, and in ten to fifteen minutes the water is absolutely safe, and has only to be rendered tasteless by the addition of sodium sulphite made into a cake or tablet…The cylinders could, of course, be refilled. This method would be of use on a large scale, as for service water carts.*' The first practical demonstration of the possibilities of this method was made by Major Carl Rogers Darnall (1867–1941) of the Medical Corps, United States Army, in 1910. He discovered the value of liquefied chlorine in purifying water for use by troops in the field. Chlorine was taken from steel cylinders and passed through automatic reducing valves which provided a uniform flow of gas for the water requiring treatment. A regular flow of water was maintained through the mixing pipe and so secured a uniform dosage. This 1910 invention, the mechanical liquid chlorine purifier (known as a *chlorinator*), was the prototype of the technology that is now applied to municipal water supplies throughout the world. The US Treasury called for all homes to have access to chlorinated water by 1918 to save the expense of sickness and epidemics. Chlorination systems were perfected by the 1930s and widely established in the United States by World War II, followed by Europe after the war.



CHEAP EXPENSIVE WATER

MANY PEOPLE dislike the smell, taste or chemical effects of chlorinated drinking water. However, much bottled water has also been chlorinated, and is much more costly. Home filtration systems can be expensive, so for a cheap alternative simply fill a bowl with tap water and put it uncovered in a refrigerator. Chlorine and related compounds will be eliminated from tap water if the container is left uncovered for 24 hours.

Chlorine in water is more than three times more effective as a disinfectant against the *E. coli* bacterium than an equivalent concentration of bromine, and more than six times more effective than an equivalent concentration of iodine. The advantage of chlorine in comparison to ozone is that the residual persists in the water for an extended period of time, allowing the chlorine to travel through the water supply system, effectively controlling pathogenic backflow contamination. Chlorine has been hailed as a saviour against cholera and various other water-borne diseases, and its disinfectant qualities have allowed communities and cities to grow by providing disease-free tap water to homes and industry.

WAVE NATURE OF LIGHT

—— 1800 ——

THOMAS YOUNG 1773–1829, ENGLAND

Young's investigation into the nature of light resulted in one of the greatest scientific breakthroughs in history. However, where does one begin when describing a polymath such as Young? He is famous for having partly

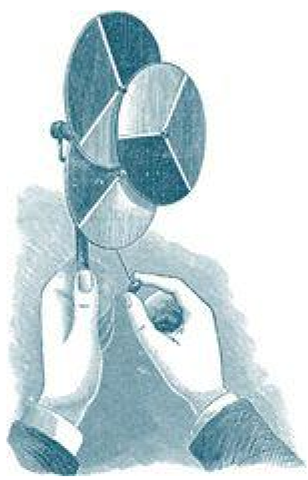
deciphered Egyptian hieroglyphics before Jean-François Champollion expanded on his work. He was admired by Herschel, Einstein and leading physicists and made notable scientific contributions to the fields of elasticity, light, vision, solid mechanics, physiology, language, musical harmony and energy. His friend, the physicist Sir John Herschel, wrote that to do justice to Young's reputation '*would call for the exercise of powers more clearly allied to his* [Young's] *own*'. As a child, by the age of 13 he had read 30 chapters of the *Book of Genesis* in Hebrew, a language he mastered without tuition. '*Whoever would arrive at excellence must be self-taught,*' he once said. He also taught himself Greek. A London bookseller, who noticed the adolescent Young engrossed in an expensive classic, said he could keep it if he could translate one page. Young duly received the book. Isaac Asimov pointed out: '*He was the best kind of infant prodigy, the kind that matures into an adult prodigy.*' Known as '*Phenomenon*' Young at Cambridge, he was only 20 in 1793 when he read a paper to the Royal Society on the way the eye accommodates to different focal distances. The eye alters the curvature of its lens through the action of muscles (a technique it loses over time, as older readers will realize when reading and having to adjust the distance at which they hold the book). Young was elected to the Royal Society aged just 21.

Between 1816 and 1825, he wrote no fewer than 63 entries for the new *Encylopaedia Britannica*, whereas his biographer states that '*very few specialists nowadays would dare to attempt more than one*'. Young wrote on the alphabet, annuities, bathing, bridge, carpentry, chromatics, cohesion, dew, Egypt, haloes, the polarization of light, road-making, ships, steam-engines, tides and waves, as well as contributing 23 biographies. Only two things he said he could not learn: '*To get up and to go to bed.*' Andrew

Robinson, who wrote a biography of Einstein, placed Young above him in achievement and versatility, giving his book about him the title: *The Last Man Who Knew Everything: Thomas Young, the Anonymous Polymath Who Proved Newton Wrong, Explained How We See, Cured the Sick and Deciphered the Rosetta Stone* (2006).

THE DAILY PATTERNS OF LIGHT

SUPPORT FOR Young's wave theory grew, and it was included in James Maxwell's theory of electromagnetic radiation. However, in 1905 Einstein's photoelectric effect showed light behaving as a stream of particles, or photons. Also electrons which were previously regarded as particles, sometimes behave like waves. Light can behave either as a wave or as particles. Both models are needed to explain the laws of physics, and in the 1920s Sir William Bragg jokingly told his students: '*On Mondays, Wednesdays and Fridays light behaves like waves; on Tuesdays, Thursdays and Saturdays like particles, and like nothing at all on Sundays.*'



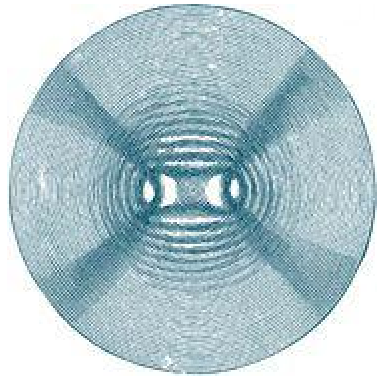
In physiology, Young made significant advances in understanding the mechanisms of the eye, explaining how it focuses, being the first to define astigmatism, and proposing the three-colour theory of how the retina detects the sensation of colour. The latter was only finally confirmed in 1959 and Young's contribution was described by a modern scientist as '*surely the most prescient work in all of psychophysics*'. In engineering, *Young's modulus* remains the engineer's measure of elasticity, explaining how

different materials contract or expand. He was superintendent of the Board of Longitude, but also kept up his medical practice, and in medicine (the one subject in which he received formal training) he also distinguished himself. *Young's rule* is still used for adjusting adult dosage to children. In music, *Young's temperament* is a technique for tuning keyboard instruments. In languages, Young coined the term *Indo-European* after a comparative analysis of 400 languages.

Young was the first man since the fall of the Roman empire to read a demotic script, and a prime mover in deciphering the Rosetta Stone, sparking the creation of Egyptology as a science. The prevailing belief was that hieroglyphics were a pictographic writing, wholly non-phonetic, its symbols representing concepts. Others, beginning with William Warburton in 1740, suggested that while the hieroglyphs might have originally been ideographs, they had become *alphabetic*. By 1814 Young had completely translated the 'enchorial' (demotic, in modern terms) text of the Rosetta Stone (he had a list with 86 demotic words). Young then painstakingly compared the demotic script with the hieroglyphs it sketchily represented. He wrote to a fellow decoder, Sylvestre de Sacy in Paris, of the '*despair of the possibility of discovering a* [demotic] *alphabet*'. He added: '*If you wish to know my "secret", it is simply this, that no such alphabet ever existed…* [the demotic script is] *imitations of the hieroglyphs…mixed with letters of the alphabet.*' While Champollion received the credit for deciphering the stone, it would not have been possible without Young's breakthrough.

STRESS AND THE HEART

YOUNG MEMORABLY remarked that '*scientific investigations are a sort of warfare…against all one's contemporaries and predecessors*' and he suffered the great hostility that polymaths often attract from academic deniers. Young's contribution to knowledge was suddenly cut short in 1829 by heart failure at the age of 55. He had made detailed hydraulic calculations relating to blood circulation in the heart and had lectured on the subject at the Royal Society in 1808.



In physics, we come to what Young himself thought was his greatest achievement. *Young's fringes* struck a blow at the great Newton, positing that light was a wave, not a stream of corpuscles. Young's revelation about light came to him when he was moving house, just as the theory of relativity came to Einstein as he moved house a century later. It is for a related experiment that Young is most famous today. By shining a light through two narrow slits and describing the pattern cast on a screen, Young demonstrated the interference of light waves. It '*showed that light added to light could produce more light – or, most surprisingly, darkness*'. The interference pattern (*Young's fringes*) could only be explained by an *undulatory* (or wave) theory of light. By the end of the century Young's theory had supplanted Newton's *corpuscular* theory. Einstein in his 1905 paper argued that light was a stream of particles, but we now know that light can behave either as a wave or as a particle. Even in the new era of quantum physics, Young's double-slit experiment has proved an invaluable demonstration of the wave-particle duality of light. Young had initially tested his ideas with water waves by building the world's first ripple tank, which today is a standard item of equipment in many physics classrooms. Two water waves could interfere to create either a 'super wave' or a point of calm depending on whether the waves were in or out of time.

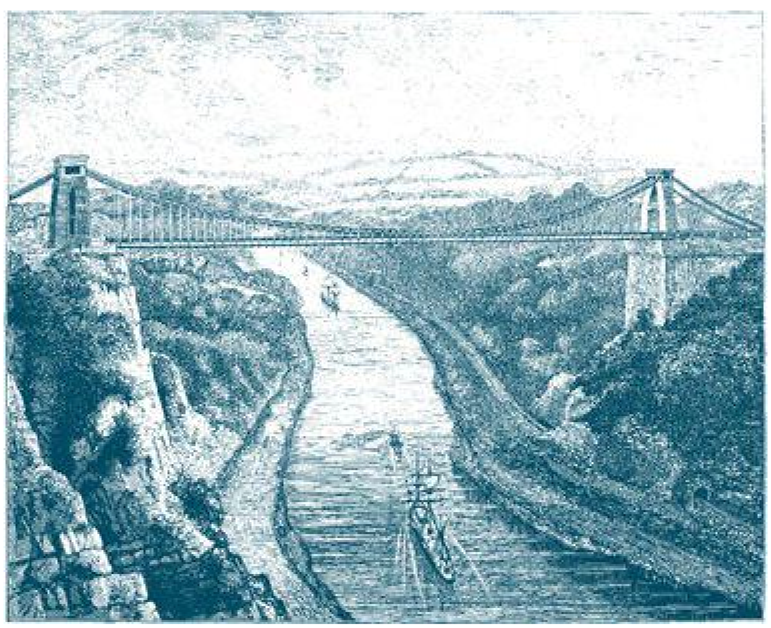
SUSPENSION BRIDGE

—— 1801 ——

JAMES FINLEY 1762–1828, MARYLAND, UNITED STATES

This type of bridge is often necessary to span deep valleys or rivers where no vertical pillars can be economically built to support it. The load-

bearing part, the *deck*, is hung below suspension cables on vertical suspenders (*hangers*). In Tibet and Bhutan simple narrow bridges using rope were built using this principle from the 15th century. James Finley was the designer and builder of the first modern suspension bridge, using towers from which to anchor the suspension cables. His Jacob's Creek Bridge in Pennsylvania was built for $600 in 1801, the first example of such a bridge using wrought-iron chains and a level deck. It was 70 feet (21.3 m) long and 12 feet 6 inches (3.8 m) wide, and spurred bridge designers across the world. It was demolished in 1833. Another of his chain suspension bridges at Dunlap's Creek in Pennsylvania collapsed owing to heavy snow and the added load of a six-horse wagon team. It was replaced by the USA's first cast-iron bridge in 1835. Finlay's's 1808 Chain Bridge at Falls of Schuykill, Philadelphia collapsed under the weight of snow in 1816, and was replaced by the world's first wire-cable suspension footbridge. Thomas Telford's Menai Suspension Bridge to the island of Anglesey, Wales spans 191 feet (58.2 m), and his elegant Clifton Suspension Bridge over the Avon at Bristol, designed in 1831, spans 231 feet (70.4 m). Both are still in use today.



THE LONGEST SUSPENSION BRIDGE

THE 1998 Pearl Bridge at Kobe, Japan has the longest central span of any suspension bridge, measuring 6532 feet (1991 m), with two other spans, each of 3150 feet (960 m). Only the central span's towers had been built by the time of the Kobe earthquake of 1995, which disturbed the towers so that the central span had to be increased by 3 feet 4 inches (1 m) when the cables were slung. The bridge's design allows it to withstand winds of up to 178 mph (286 kph), incredibly strong tidal currents and earthquakes up to 8.5 on the Richter Scale. Its steel cables contain 190,000 miles (305,800 km) of wire, each cable being 44 inches (112 cm) in diameter and containing 36,830 strands of wire.

INTERCHANGEABLE PARTS

—— 1802 ——

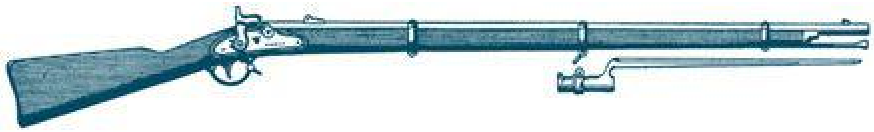
MARC ISAMBARD BRUNEL 1769–1849, FRANCE AND ENGLAND

Mass production depended on interchangeable, standardized parts, a development that accelerated the Industrial Revolution and enabled the *assembly line*. Parts for manufacturing are precision-made to identical specifications so that they will fit into any device of the same type. One such part can freely replace another, without any custom fitting, allowing simple assembly of new devices, and their easier repair, while minimizing the time and skill required. Interchangeability was crucial to the introduction of the assembly line by Henry Ford from 1908, which enabled modern manufacturing methods. Devices such as guns had traditionally been made by gunsmiths, with each gun being unique, expensive and having to be returned to the maker for repairs. In 1778 Honoré Blanc demonstrated in France that his muskets could be assembled from a pile of parts selected at random. In 1801 Eli Whitney carried out a similar demonstration for the US Congress, but his guns had been made by hand at great cost.

In 1796 the French refugee Marc Brunel (the father of Isambard Kingdom Brunel) was appointed New York City's Chief Engineer. Learning of the Royal Navy's difficulties in sourcing 100,000 handmade pulley blocks each year to fit out its ships, he designed a machine to automate their production. He sailed to England and met Henry Maudsley, a machine tool maker who then made working models of Brunel's machines. A total of 45 new block-making machines were installed near the naval base at Portsmouth in 1802. Using unskilled operators, the rate of production rose tenfold, and by 1808 the plant was producing 130,000 blocks a year. From 1816, milling machines developed by Simeon North and others allowed the machining of metal to high tolerances, permitting the mass production of complex machines with moving parts such as rifles. The system for producing interchangeable parts is sometimes called '*the American system of manufacturing*', because it was first most fully developed in the USA.

THE SPRINGFIELD RIFLE

BY THE end of the American Civil War, around 1.5 million Springfield rifle muskets had been produced by the Federal Springfield Armory in Massachusetts and 20 subcontractors. The Confederacy lacked manufacturing capacity, using imported Enfield muskets, which did not benefit from the interchangeability of parts of the machine-made Springfields. Some historians believe that the Springfield rifle musket was the deciding factor in the Civil War.



ATOMIC THEORY

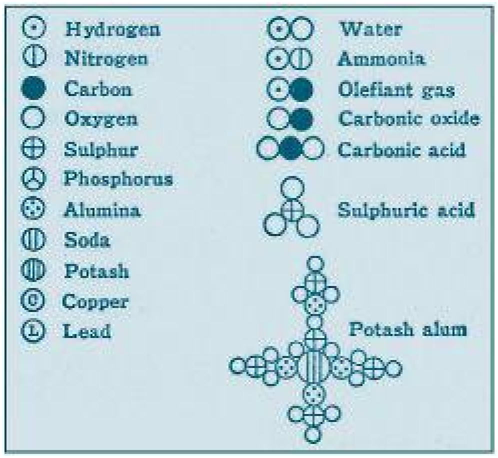
—– 1803 —–

JOHN DALTON 1766–1844, ENGLAND

A Quaker, Dalton taught mathematics and natural philosophy in Manchester. He altered his research interests from meteorology to chemistry when he saw the applications to chemistry of his ideas about the atmosphere. This resulted in Dalton studying gases, which led him to the formulation of the atomic theory in 1803. This theory stated that all matter was composed of small, indivisible and indestructible particles termed atoms. Secondly, he stated that the atoms of one element are all exactly alike in every respect including weight, but are different from the atoms of every other element, i.e. atoms of a given element possess unique characteristics and weight. Thirdly, when elements combine to form compounds their atoms combine in simple numerical proportions such as one to one, two to one, and four to three. He said that three types of atoms exist: simple (elements), compound (simple molecules), and complex (complex molecules). Dalton's theory was presented in his *New System of Chemical Philosophy* (1808–27). This work identified chemical elements as a specific type of atom, thus rejecting Newton's theory of chemical affinities. Dalton proposed, following Richter's idea, that chemical elements combine in integral ratios. He speculated that the major difference between atoms was their masses and tried to work out the relative weights of different atoms from the proportions by weight of the elements in certain compounds, so becoming the first person to prepare a table of atomic weights. Dalton inferred proportions of elements in compounds by taking ratios of the weights of reactants, setting the atomic weight of hydrogen to be one. This was the first view of atoms as physically real entities.

DALTON AND COLOUR BLINDNESS

JOHN DALTON WAS elected to the Manchester Literary and Philosophical Society at 27, to which body he then read his paper giving the first account of colour blindness, from which he suffered. What makes this paper so remarkable is that a deficiency in colour perception, colour blindness, had not even been formally described or officially noticed by the scientific community, until Dalton wrote about his own visual problem. Colour blindness is sometimes called *Daltonism*.



WHERE DALTON WAS WRONG

ALL BUT two of the statements in Dalton's Atomic Theory are considered valid today. His first error is the statement '*Atoms cannot be subdivided, created, or destroyed into smaller particles when they are combined, separated, or rearranged in chemical reactions.*' This is now inconsistent with the existence of nuclear fusion and fission. Also the statement '*All atoms of a given element are identical in their physical and chemical properties*' is not precisely true, as the different isotopes of an element have varying numbers of neutrons in their nuclei, though the number of protons remains consistent.

The ideas of atoms had been suggested centuries earlier by Democritus, but Dalton's complete formulation of a consistent theory was a breakthrough. He also drew up a system of notations to represent elements, discarding the obscure drawings that had been handed down from alchemists of ancient times. He created clear symbols to stand for the atoms

of different elements, and used them in drawings which showed what took place during chemical reactions. For example, molecules were shown as groups of atom symbols linked together. In 1803 Dalton noted that oxygen and carbon combined to make two compounds, carbon oxide and carbon dioxide. Of course, each had its own particular weight ratio of oxygen to carbon (carbon oxide 1.33:1 and carbon dioxide 2.66:1), but also, relative to the same amount of carbon, one had exactly twice as much oxygen as the other. This led him to propose the Law of Multiple Proportions (Dalton's Law), which was later verified by the Swedish chemist Jöns Jacob Berzelius. However, it was another century before atomic theory was accepted by all scientists. Dalton's conceptual revolution established the model for today's chemists and physicists.

CANNING PROCESS

—– 1810 —–

NICOLAS APPERT 1749–1841, FRANCE, AND PETER DURAND FL. 1810, ENGLAND

Airtight food preservation has greatly benefitted the health of nations, enabled exports of food and allowed people to eat produce out of season. In 1795 the French government offered a prize of 12,000 francs to anyone who could invent a method of preserving food. More troops were dying of hunger and scurvy than in combat, and the expansion of the empire required a way of keeping food unspoiled so that it could be transported considerable distances and opened many weeks after its initial preparation. A Parisian confectioner named Nicolas Appert experimented for 15 years, eventually successfully preserving food by partially cooking it, sealing it in bottles with cork stoppers and sealing wax, and immersing the bottles in boiling water. Appert had correctly assumed that, as with wine, exposure to air spoiled food. Therefore, food in an airtight container, with the air expelled through the boiling process, would stay fresh. Samples of Appert's preserved food were sent to sea with Napoleon's troops for a little over four months – partridges, vegetables and gravy were among 18 different items sealed in glass containers. All retained their freshness. '*Not a single substance had undergone the least change at sea*', Appert wrote of the trial. He was awarded the prize in 1810 by Emperor Napoleon. Also in 1810,

Appert published *L'Art de conserver les substances animales et végétales* ('The Art of Preserving Animal and Vegetable Substances'), the first cookbook of its kind on modern food preservation methods. La Maison Appert near Paris became the first food-bottling factory in the world, more than 50 years before Louis Pasteur proved that exposure to heat killed bacteria.

Also in 1810, an Englishman of French origin named Peter Durand was granted a patent from King George III for preserving food in '*vessels of glass, pottery, tin or other metals or fit materials*'. Durand believed that he could fashion containers out of tinplate, which would be easier to transport and store than Appert's glass cans (now known as jars). Made of iron coated with tin to prevent rusting and corrosion, tinplate could be sealed and made airtight, and was not breakable like glass. A cylindrical canister and soldered lid would be much easier to handle than a fragile bottle with an unreliable cork. Two other Englishmen, Bryan Donkin and John Hall, bought Durand's patent and, after more than a year of experimentation, set up the first commercial canning factory using tinplate cans in Bermondsey, London in 1812. If the French military was able to travel further and last longer on its provisions, then the British needed to be able to do so as well. By 1813 Donkin's tins of preserved food were supplying the British army and navy. The nutritious canned vegetables were a great relief to sailors who previously had relied on live animal cargo or salted meat for their sustenance, and were often plagued by debilitating scurvy. By 1820 canned food was a recognized article in Britain and France and by 1822 in the United States.

HOW TO OPEN A CAN

TIN CAN mass-production was not common until the later 19th century, partly because they were difficult to open. The instruction on early cans read '*Cut round the top near the outer edge with a chisel and hammer*'. The year 1855 saw the invention of a can opener by Robert Yeates in 1855. A cutlery and surgical instrument maker, he devised the first claw-ended can opener with a hand-operated cutter that moved its way around the top of metal cans. Later designs work on a lever principle, usually with a butterfly wheel.

No cans currently in wide use are composed primarily or wholly of tin. Until the second half of the 20th century, tinplate steel was used in cans, as it combined the physical strength and relatively low price of steel with the corrosion resistance of tin. Use of aluminium in cans began in 1957. Aluminium is less costly than tin-plated steel but offers the same resistance to corrosion in addition to greater malleability, resulting in ease of manufacture. Thus we now have the two-piece can, where all but the top of the can is simply stamped out of a single piece of aluminium, rather than laboriously constructed from two pieces of steel. Often the top is tin-plated steel and the rest of the can aluminium.

HIGH-PRECISION MACHINE TOOLS

—— 1817 ——

RICHARD ROBERTS 1789–1864, WALES

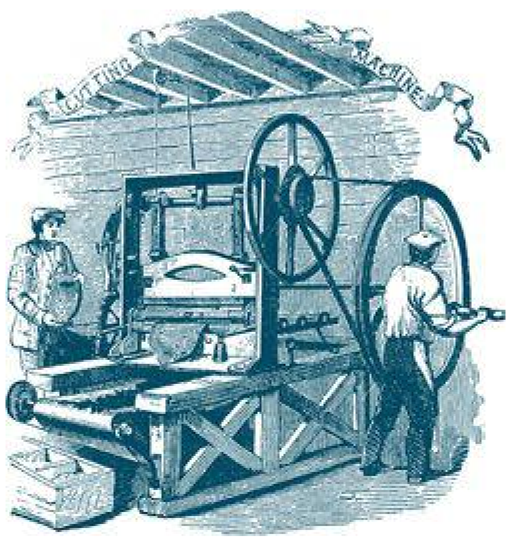
Richard Roberts was possibly the most important mechanical engineer of the 19th century. Born near Llanymynech in Wales, this virtually unknown inventor and innovator received only a rudimentary education. He found a job as a pattern-maker at Bradley Ironworks, Staffordshire. To avoid being forced into the militia during the Napoleonic Wars, Roberts moved to Birmingham, Liverpool, Manchester, Salford and London, before returning to Manchester in 1816, where he set up his own workshop. After making a successful gas meter for Manchester, where others had failed, he moved on

to other inventions. Through lack of finance, he could not patent his meter, and it was copied by Samuel Clegg in London as a water meter, then also as a gas meter. One of Roberts's first tasks in his own business was to make himself a gear-cutting machine, and a sector to measure the gear blanks accurately. His first commercial work seems to be the manufacture of letterpresses. Creating their flat surfaces inspired the invention of his metal planing machine tool of 1817, which he sold to other companies and engineers. Previously, flat surfaces were laboriously made by hand with the fitter using hammers and chisels, files and scrapers to get a true surface. Roberts also realized the potential of such machines for generating flat surfaces at angles in addition to the horizontal. He also adapted it to plane curves and spirals, so making the planer essential in the engineering workshop. His planer is now in the Science Museum in London.

In 1817 Roberts also designed a metal-turning lathe with innovative features and, in 1820, a screw-cutting lathe. His centre lathe was capable of turning metal articles 6 feet (1.82 m) long and 18 inches (46 cm) in diameter. It was fitted with back-gearing and was probably the first of its type. Roberts also built special lathes for screw-cutting as well as centre lathes with rack or screw traverse motions, the latter being capable of cutting screws. These again were offered for sale in a range of sizes. Both types of lathe continued in use in the Beyer-Peacock factory into the 20th century and are in the Science Museum. In 1818 Roberts produced a breech-loading rifled cannon for a Mr Bradbury. In 1821 he placed an advertisement in the first issue of the *Manchester Guardian* for an improved gear-cutting machine, one of which is preserved in the collections of the Science Museum in London.

Not content with inventing planing, turning, screw-cutting and gear-cutting machine tools, Roberts turned his attention to weaving, and in 1822 patented a power loom. Output is thought to have reached 4000 a year by 1825. Such a volume needed batch or semi-mass production techniques as well as special machine tools, and it was supplied to many spinning companies at home and overseas. On his power looms, pulley and gear wheels had to be secured to their shafts by keys. To cut the slots for these, Roberts introduced his *keyway grooving machine* in 1824, which was later improved into his more versatile *slotter* in 1825. The slotting machine cut keyways in gears and pulleys to fasten them to their shafts, which previously was done by hand chipping and filing. The tool was reciprocated

vertically. By adopting Henry Maudslay's slide-rest principle, Roberts made the work table with a universal movement, both straight line and rotary, so that the sides of complex pieces could be machined. Later he developed the *shaping machine*, where the cutting tool was reciprocated horizontally over the work, which could be moved in all directions by means of screw-driven slides. Roberts also manufactured and sold sets of stocks and dies to his range of pitches, so other engineers could cut threads on nuts and bolts and other machine parts. A blowing engine for furnaces in foundries, like an Archimedean screw, and the first of his punching and shearing machines followed soon afterwards.

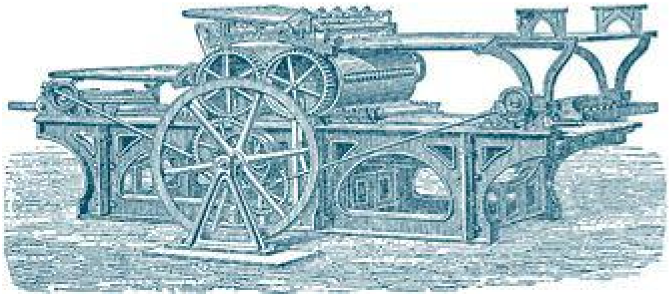


Thus a power loom, slotting machines, shaping machines, punching and shearing machines were added to his portfolio of inventions. In 1825 Roberts patented his first design of a *self acting* (automatic) spinning mule. Because of a strike of skilled mule spinners, local mill owners had asked Roberts to make the mule work automatically, but he at first refused. He relented and, but for a disastrous fire at the Globe Works in the summer of 1825, would have had it running then. It did not prove as successful as hoped, but Roberts designed standard templates and gauges to secure accuracy in its manufacture. These became features in Roberts's later manufacture of other products, such as railway locomotives and much more. This idea was quickly copied by others. A further patent for the spinning mule which included his intricate *quadrant winding mechanism* was granted in 1830. It brought limited financial success because of its

costs of development. It was a superb solution to a complex problem, and remained little altered and in production for over 100 years.

Roberts had carried out experiments on the friction of railway wagons in 1825, and constructed a steam road carriage capable of carrying 35 passengers, which he trialled in 1834. He next designed and built several railway locomotives, and his 1835 design of 2-2-2 tender locomotives was ordered by many railway companies both in Britain and on the continent. Roberts invented cylindrical slide valves, patented in 1832, at the same time as a variable expansion gear for steam engines and a differential gear for road locomotives. He also invented a steam brake. His locomotives were built to high engineering standards, had strong frames and large bearing surfaces. Roberts was probably the first British engineer to apply weights to driving wheels to balance revolving masses. Demand became so great that it could not be met and a new factory had to be built. Roberts continued with his standardization of as many parts as possible, so that they could be manufactured on specially designed (dedicated) machine tools.

As well as nut- and bolt-making machines, Roberts now introduced new shaping machines, plate-rolling machines and improved punching and shearing machines. He was in advance of his era as he designed tools with rotary cutters, similar in principle to modem milling machines, for producing his crankshafts, with hexagon heads on bolts as well as oil grooves in bearings. He also had a wide variety of drilling machines and is credited with inventing the extremely important *radial arm drill*. Roberts continued with patenting improvements in the textile industry for combing machines, new looms and finishing machines. He invented a cigar-rolling machine and presented a paper about a design for a floating lightship. Roberts’s most famous invention at this period was the *Jacquard punching machine* (as it worked on the same principles as a Jacquard loom) for punching the rivet holes in the iron plates making up the railway bridge at Conwy in Wales. This plate-punching machine made possible the rapid construction of the Conwy and Britannia tubular bridges. The regular rivet holes enabled the steel plates to match exactly with each other.



Meters for liquids, turbines, clock mechanisms, chronometers, machines for drilling watch plates and many more inventions were featured in his patents during this period. Roberts now realized that iron ships could be built on similar principles to the tubular bridges, with tubes acting as strengthening girders. He secured a patent in 1852 for a very advanced design of liner to carry 500 passengers which, if it had been built, would have been the largest ship afloat. The patent contained claims for a wide range of novelties in both merchant and naval ship design. Twin screws capable of being worked independently for greater manoeuvrability were another feature which Roberts advocated. One ship at least, the SS *Flora*, was fitted with his twin screws and showed great manoeuvrability when employed as a blockade runner in the American Civil War. Roberts made several visits to France to set up a factory in Alsace for a firm of textile manufacturers, which changed to manufacturing machinery. He returned to England, and then proposed designs for ships and men of war to improve their functioning and internal servicing, and to make them less vulnerable to enemy fire. Roberts established about 30 patents taken out in a space of 28 years, and worked until the end of his life, but he died in poverty.

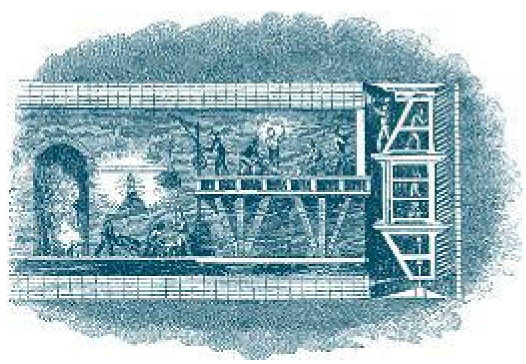
TUNNELLING SHIELD

—— 1818 ——

MARC ISAMBARD BRUNEL 1769–1849, ENGLAND

A tunnelling shield is the protective structure necessary to excavate tunnels through soft or fluid soil. It gives stability for the time it takes to line the tunnel with a support structure of concrete, cast iron or steel. This first temporary support structure for a tunnel was developed by Brunel and patented by him and Lord Cochrane in 1818. Working with his more famous son, Isambard Kingdom Brunel, in 1825 Sir Marc Brunel used it to

excavate the Thames Tunnel, which opened in 1843. The reinforced shield of cast iron allowed miners to work in separate compartments, digging at the tunnel-face. The shield was driven forward by large jacks, and the tunnel surface behind it would be covered with cast-iron lining rings. Bricklayers followed, lining the wall with 7.5 million bricks. The tunnel is now part of the East London Line of the London Underground. Henry Maudslay made the tunnelling shield and supplied steam-powered pumps. Some believe that Brunel found the inspiration for his tunnelling shield from *Teredos* shipworms he had seen at London docks. The creature's head is protected by a hard shell while it bores through ships' timbers with its teeth. The early deep tunnels for the London Underground were built using this method. The shield divided the workface into overlapping portions that each worker could excavate. The invention allowed tunnelling to be carried out in any type of geological conditions. Brunel's design has been improved over the years, but all tunnelling shields use the same principles.



THE SEA WOLF

ADMIRAL LORD Thomas Cochrane, Brunel's co-patentee, was the most daring sea captain of the Napoleonic Wars, leading the French to call him *le loup des mers*, the wolf of the seas. Dismissed from the Royal Navy in 1814, he led the navies of Chile, Brazil and Greece in their fights for independence. In 1832 he was reinstated, becoming rear-admiral. His exploits provided the inspiration for C.S. Forester's Captain Horatio Hornblower and Patrick O'Brian's Captain Jack Aubrey.

FRICTION MATCH

— 1826 —

JOHN WALKER 1781–1859, STOCKTON-ON-TEES, ENGLAND

In 1819 Walker opened a chemist's and druggist's shop in Stockton-on-Tees. He discovered that if he coated the end of a stick with certain chemicals and let them dry, he could start a fire by striking the stick against any rough surface. These were the first friction matches. The chemicals he used were antimony sulphide, potassium chlorate, gum and starch. Walker did not patent his *Congreves* as he called the matches (referring to the Congreve's rocket invented in 1808), preferring instead to pursue his scientific studies. However, he did not divulge the exact composition of his matches. Walker sold his first *Friction Light* on 7 April 1827 to a local solicitor, from his pharmacy in Stockton. These first friction matches were made of cardboard but he soon began to use wooden splints cut by hand. The price of a box of 50 matches was one shilling (the equivalent of 5 pence today). Each box was supplied with a piece of sandpaper, folded double, through which the match had to be drawn to ignite it. It proved a simple, but effective, boon for mankind for lighting combustibles and gas.

PACK UP YOUR TROUBLES

THE CHORUS of the popular First World War song refers to lucifers:

'Pack up your troubles in your old kit-bag,
And smile, smile, smile,
While you've a lucifer to light your fag,
Smile, boys, that's the style.
What's the use of worrying?
It never was worth while, so

Pack up your troubles in your old kit-bag,
And smile, smile, smile.'

According to Isaac Asimov's *Book of Facts*, Walker rejected the idea of patenting his creation, citing the benefit that useful matches could have to mankind. Walker said that matches were better left to public and free use by all humanity, rather than being exploited by those who owned the manufacturing rights. Samuel Jones from London saw Walker's 'Congreves' or 'Friction Lights' and decided to patent and market them, calling his matches *Lucifers*. Lucifers became popular especially among smokers, but they gave off a bad smell while burning and had an unsteady flame. Also the initial reaction upon sparking was disconcertingly violent. Lucifers reportedly could ignite explosively, sometimes scattering sparks a considerable distance. In Belgium and the Netherlands, matches are still called lucifers. In 1830 the Frenchman Charles Sauria added white phosphorous to matches to remove the odour of sulphur. The new matches had to be kept in an airtight box but they proved popular. Unfortunately, those involved in the manufacture of the new matches were afflicted with *phossy jaw* (phosphoric necrosis of the jaw) and other bone disorders, and there was enough white phosphorus in one pack to kill a person.

THE SAFETY MATCH 1844

EARLY MATCHES were dangerous to both their end users and the workers that made them. White phosphorous could stick to the skin, and any associated burns could lead to organ damage as phosphorous was absorbed into the body. The search for a replacement for white phosphorus, as laws were passed banning its use, led to what was known as the *safety match*.

It was invented in 1844 by the Swede Gustaf Erik Pasch (1788–1862) and was improved by the Lundström brothers who had started a large-scale match industry in Jönköping around 1847. Their improved safety match was not introduced until around 1850–5. In 1858 their company produced around 12 million match boxes. Safety is ensured because of the separation of the reactive ingredients between a match head on the end of a paraffin-impregnated splint and a special striking surface on the side of the match box. Furthermore the dangerous white phosphorus was replaced with safer red phosphorous. The striking surface is composed of around 25 per cent

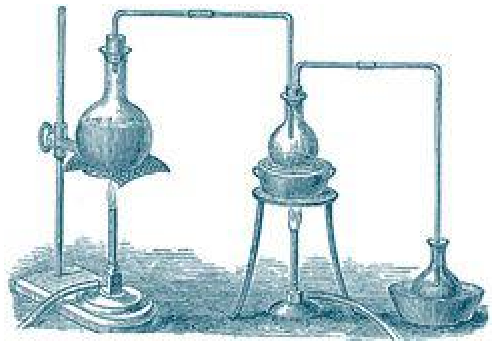
powdered glass, 50 per cent red phosphorus, 5 per cent neutralizer, 4 per cent carbon black and 16 per cent binder. The match head is typically composed of 45–55 per cent potassium chlorate, 20–40 per cent of siliceous filler and small quantities of sulphur, starch, diatomite, glue and a neutralizer. Safety matches ignite due to the extreme reactivity of phosphorus with the potassium chlorate that is contained in the match head. The Swedes long held a virtual worldwide monopoly on the production of safety matches.

WÖHLER SYNTHESIS AND THE DISPROOF OF VITAL FORCE TH EORY

—— 1828 ——

FRIEDRICH WÖHLER 1800–1882, GERMANY

This German professor demonstrated that organic compounds could be synthesized from inorganic compounds. Wöhler was a pioneer of organic chemistry, best known for the *Wöhler Synthesis* of urea in 1828. From ancient Egyptian and Classical times it was believed that there was a spark, or *vital force* in living organisms, and compounds were divided into organic and inorganic classes. This concept of *vitalism* followed Aristotle's distinction between the animal, vegetative and mineral kingdoms. Scientists still believed that the difference was so fundamental between organic and inorganic materials, that (live) organic compounds could not be synthesized from (dead) inorganic compounds. However, Wöhler prepared crystals of urea, a constituent of human urine, from ammonium cyanate in his laboratory, without the help of a living cell. He had been attempting to prepare ammonium cyanate from silver cyanide and ammonium chloride, and thus had accidentally carried out the first organic synthesis. He discovered that urea and ammonium cyanate had the same chemical formula, but very different chemical properties, an early discovery of isomerism. Wöhler then wrote to Jöns Jakob Berzelius, his former teacher and the champion of vital force theory, that he had seen '*the great tragedy of science, the slaying of a beautiful hypothesis* [vital force theory] *by an ugly fact*'. The Wöhler Synthesis was a landmark in the history of science as it disproved vital force theory by demonstrating that organic compounds could be synthesized from inorganic materials.



THE SCIENTIFIC AMERICAN TRIBUTE

FROM 1820 to 1881 Wöhler continuously contributed to scientific journals, and on his death in 1882, the *Scientific American* stated that: '… *for two or three of his researches he deserves the highest honor a scientific man can obtain, but the sum of his work is absolutely overwhelming. Had he never lived, the aspect of chemistry would be very different from that it is now.*'

He was also recognized for being the discoverer or co-discoverer of silicon, yttrium, titanium, aluminium, silicon nitride and beryllium. In 1834, with Justus von Liebig, he proved that a group of carbon, hydrogen and oxygen atoms can behave like an element, and be exchanged for elements in chemical compounds. This underpinned the doctrine of *compound radicals*, profoundly influencing the development of chemistry. In 1862 Wöhler also discovered that the reaction of water with calcium carbide produced *acetylene*, a process now used for manufacturing PVC. He also found methods of separating nickel and cobalt from their ores in a state of purity.

ELECTROMAGNETIC INDUCTION

—— 1831 ——

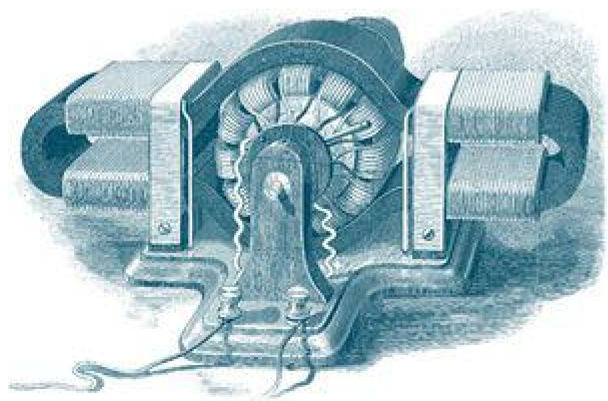
MICHAEL FARADAY 1791–1867, ENGLAND

Faraday's inventions of electromagnetic rotary devices formed the basis of electric motor technology, and it was largely owing to Faraday's inventions of the transformer and generator that electricity became used in technology. Unlike the 'gentlemen scientists' of his era, independently

wealthy, well-educated men to whom science was a hobby, Faraday came from a poor family. Apprenticed to a bookbinder, he read books borrowed from work, including the ‘electricity’ section of *Encyclopaedia Britannica* and Jane Marcet’s *Conversations on Chemistry*. One of the bookbinder’s customers gave Faraday free tickets to lectures given by the eminent chemist Sir Humphry Davy at the Royal Institution in London. Faraday conceived the goal of working for the great scientist, and on the basis of Faraday’s carefully taken notes of his lectures, he was hired by Davy in 1813. Faraday developed as an analytical and practical chemist, and in 1825 he replaced the seriously ill Davy in his duties, directing the laboratory at the Royal Institution. In 1833 he was appointed to the Fullerian Professorship of Chemistry, a special research chair created for him at the Royal Institution. Among other achievements, Faraday liquefied various gases, including chlorine and carbon dioxide. His investigation of heating and illuminating oils led to his discovery of benzene and other hydrocarbons, and he experimented at length with various steel alloys and optical glasses.

Faraday is most famous for his contributions to the understanding of electricity and electrochemistry. In this work he was driven by his belief in the uniformity of nature and the inter-convertibility of various forces, which he conceived early on as fields of force. In 1821 he succeeded in producing mechanical motion by means of a permanent magnet and an electric current. This electromagnetic rotation was the principle behind the electric motor. Unfortunately, pressures of other work meant that Faraday had little time to experiment in the 1820s. In 1831 he converted magnetic force into electrical force, thus inventing the world’s first electrical generator. This electromagnetic induction is also the principle behind the transformer. In the course of proving that electricity produced by various means is identical, Faraday discovered the two laws of electrochemistry. Firstly, the amount of chemical change or decomposition is exactly proportional to the quantity of electricity that passes in solution. Secondly, the amounts of different substances deposited or dissolved by the same quantity of electricity are proportional to their chemical equivalent weights. Faraday is credited with discovering electromagnetic induction, diamagnetism and laws of electrolysis. In 1833 Faraday and William Whewell worked out a new nomenclature for electrochemical phenomena based on Greek words, such as ion, electrode, anode, cathode and so on. Faraday suffered a nervous

breakdown in 1839 but eventually returned to his electromagnetic research, this time on the relationship between light and magnetism. He found that magnetism could affect rays of light and there was a relationship between the two phenomena. Although Faraday was unable to express his theories in mathematical terms, his ideas formed the basis for the electromagnetic field concept (classical field theory) and equations that James Clerk Maxwell developed in the 1850s and 1860s. He is thought one of the best experimentalists in history, and was a hugely influential figure, revered by scientists such as Einstein.



REFRIGERATOR/FREEZER

—– 1834 —–

JACOB PERKINS 1766–1849, MASSACHUSETTS

The availability of frozen foods has revolutionized our eating habits, with food being transported all over the world. Before the invention of the refrigerator, rich people used icehouses to provide cool storage for most of the year. They were placed near freshwater lakes, or packed with snow and ice during the winter. Later on people were able to buy ice, and keep it in ice-boxes. In 1748 William Cullen at the university of Edinburgh used a pump to create a partial vacuum over a container of diethyl ether, which then boiled, absorbing heat from its surroundings. He created a small amount of ice, but could see no practical application. Jacob Perkins worked closely with the great American-Welsh inventor Oliver Evans (1755–1819), who designed the first refrigerator which used vapour instead of liquid in 1805, but who never built it. Perkins re-examined Evans's work and is credited with the first patent for the '*vapour-compression refrigeration*

cycle' in 1834, titled '*Apparatus and means for producing ice, and in cooling fluids*'. Perkins was the first to describe how pipes filled with volatile chemicals whose molecules evaporated very easily could keep food cool, like wind chilling the skin after a dip in the sea. However, he neglected to publish a technical description of his invention and its evolution was slow. Around 1850, John Gorrie demonstrated an ice-maker, and in 1857 the Australian James Harrison designed the world's first practical ice-making machine and refrigeration system, which was used in the brewing and meat-packing industries of Victoria State.

Two Swedish students designed the absorption refrigerator in 1922, and it became a worldwide success, being commercialized by Electrolux. Absorption fridges are powered by a heat source that drives the cooling system. Compressor fridges use electricity. Carl von Linde's work upon the liquefaction of air, patented in 1895, allowed the manufacture of the first practical compact fridges. By 1922, a home refrigerator cost about 50 per cent more than a Model T Ford car, and ice cube trays were being introduced into the design. The compressor assemblies on early fridges generated a great deal of heat, so were often placed on top of the unit. The introduction of Freon in the 1920s expanded the refrigerator market during the 1930s, and provided a safer, low-toxic alternative to previously used refrigerants. From the late 1920s fresh vegetables were successfully processed through freezing by the forerunner of General Foods, which had acquired the technology when it bought the rights to Clarence Birdseye's successful fresh freezing methods. Home freezers as separate compartments (larger than those necessary just for ice cubes), or as separate units, were

introduced in the United States in 1940. Frozen foods, previously a luxury item, began to become commonplace in the USA.

FRIDGE PENETRATION LEVELS

COMMERCIAL FRIDGE and freezer units were in use for almost 40 years prior to the appearance of domestic models. They used toxic gas systems, which occasionally leaked, making them unsafe for home use. Practical household refrigerators were introduced in 1915, and they gained wide acceptance in the United States in the 1930s as prices fell, and as non-toxic, non-flammable synthetic refrigerants were introduced. While 60 per cent of households in the United States owned a refrigerator by the 1930s, it was not until 40 years later, in the 1970s, that the refrigerator achieved a similar level of penetration in the United Kingdom, possibly because of the slower adoption of electricity and the wide variety of local food shops.

A refrigerator is basically a thermally insulated compartment, with a heat pump which transfers heat from inside the fridge, so that the interior of the fridge is cooled to a temperature below the ambient temperature of the room. Low temperatures reduce the reproduction rate of bacteria, so foodstuffs can be kept longer without spoiling. A fridge maintains a temperature a few degrees above the freezing point of water, around 37–41° F (3–5° C). A freezer maintains a temperature below the freezing point of water, and allows us to buy and store food in bulk for longer periods. Fridge-freezers should allow us a far more varied diet and thus improved health, but studies of the correlation between microwaved frozen ‘fast foods’ and obesity have proved that access to easy meals has led to a general decline in overall health.

ANALYTICAL ENGINE

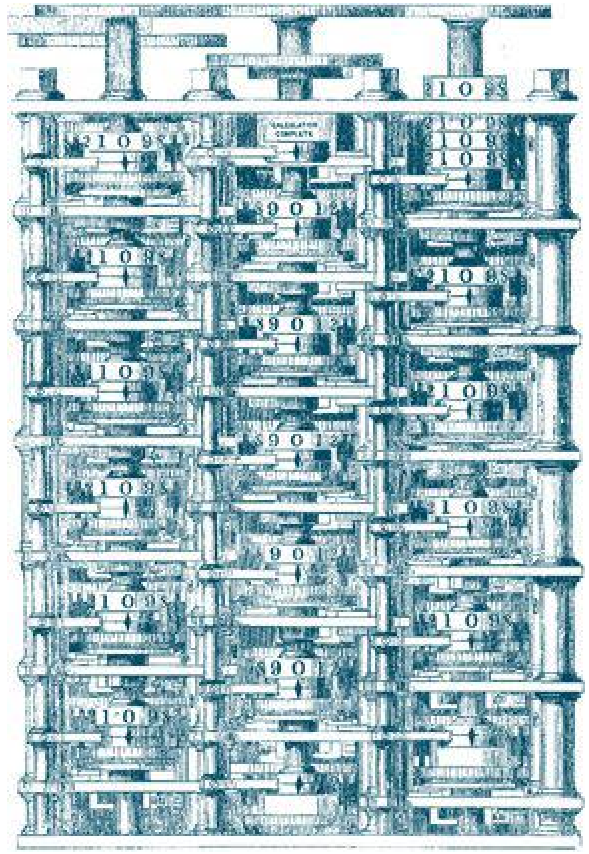
—— 1834–1871 ——

CHARLES BABBAGE 1791–1871, ENGLAND

From 1828 to 1839 Babbage was Lucasian Professor of Mathematics at Cambridge. Until the successful automation of calculation in the 20th century, scientists, navigators, engineers, surveyors, actuaries and the like relied on printed mathematical tables to perform calculations requiring

more than a few figures of accuracy. Babbage's reputation as a computer pioneer rests on his work on automatic calculating engines of two kinds: *Difference Engines* and *Analytical Engines*. By previous standards these engines were monumental in conception, size and complexity. In 1821 Babbage began the task of mechanizing the production of mathematical tables. Their compilation was not only laborious but also prone to error both in their original content, and in their printing and finally in their copying from the printed version. His idea was that a calculating machine that could not only calculate without error, but automatically print the results would eliminate at a stroke all three sources of errors in printed tables.

Babbage therefore designed an apparatus called a difference engine. The engine was not designed to perform basic arithmetic, but to calculate a series of numerical values and automatically print the results. Difference engines were designed to calculate using the *method of finite differences*, a well-used principle of the time. The advantage of using the 'method of differences' is that it eliminated the need for multiplication and division in the calculation of a particular class of mathematical functions called polynomials. The difference engine only used addition, which is easier to mechanize than multiplication and division. The design specification for the full size *Difference Engine No. 1* required an estimated 25,000 parts, which would have had a combined weight of some 13 tons. A six-wheeled model was initially constructed and demonstrated to a number of audiences. Babbage hired Joseph Clement, a skilled toolmaker and draughtsman, to build the engine. The only section of the engine to be completed was finished in 1832, and is among the most celebrated icons in the prehistory of computing. It is the oldest surviving automatic calculator, and among the finest examples of precision engineering of the time.



By the end of 1834 *Difference Engine No. 1* was still incomplete, but Babbage had now conceived the analytical engine. This was the revolutionary machine on which his fame as a computer pioneer now rests. The analytical engine was far more ambitious and technically demanding but, like the difference engine, little of it was ever built. It was intended to be able to perform any arithmetical calculation using punched cards that would deliver the instructions. It was also to have a memory unit to store numbers, and many other components that are fundamental to today's computers. All that survives are a few partially completed mechanical assemblies and test models of small working sections. The ground-breaking work on the analytical engine was largely complete by 1840. In 1847 he began the design of *Difference Engine No. 2*, using elegant and simplified techniques which he had developed for the more complex analytical engine. The difference engines were automatic, in that they did not rely (as did previous manual calculators) on the continuous informed intervention of a human operator to achieve useful results. The difference engines were the first designs to successfully embody mathematical rule in mechanisms, but they were not general-purpose machines. They could process numbers

entered into them only by adding them in a particular sequence. However, the analytical engine was not only automatic but also general purpose, in that it could be *programmed* by the user to execute a repertoire of instructions, in any required order. The engine was envisaged as a universal machine for finding the value of almost any algebraic function. It is not a single physical machine but a succession of designs that Babbage refined until his death in 1871.

The designs for his constantly improved analytical engine include almost all the essential logical features of a modern electronic digital computer. It was programmable using punched cards, had a *store* where numbers and intermediate results could be held and a separate *mill* where the arithmetic processing was performed. The separation of the 'store' (memory) and 'mill' (central processor) is a fundamental feature of the internal organization of modern computers. His engine *looped*, i.e. it could repeat the same sequence of operations a predetermined number of times. It was also was capable of *conditional branching*, so it could automatically take alternative courses of action depending on the result of a calculation (what we now call IF… THEN… statements). It would have needed to be operated by a steam engine of some kind. Babbage made little attempt to raise funds to build the analytical engine. Instead he continued to work on simpler and cheaper methods of manufacturing parts and built a small trial model, which was under construction at the time of his death. Babbage failed to complete the construction of any of his engines, as manufacturing the intricate parts stretched the standards of engineering practice of the time. The shapes required special jigs and tools and the engines' mechanisms demanded hundreds of near-identical precision parts. Babbage conceived his engine designs at a time when production techniques were in transition between craft traditions and mass-production, so the means of producing repeated parts automatically were not yet available.

THE FIRST COMPUTER PROGRAMMER WAS LORD BYRON'S DAUGHTER…

IN 1842, an Italian engineer and mathematician, Louis Menebrea, published a memoir in French on the subject of the analytical engine. Babbage appointed Augusta Ada King, Countess Lovelace, who is known simply as Ada Lovelace (1815–1852), to translate the article. She was the

only legitimate child of Lord Byron. Lovelace added a series of in-depth notes (longer than the original memoir), and demonstrated a level of understanding which perhaps even Babbage himself had not achieved. Babbage was incredibly impressed, writing ‘*Forget this world and all its troubles and if possible its multitudinous Charlatans – every thing in short but the Enchantress of Numbers.*’ Babbage also addressed her in a letter as ‘*my dear and much admired interpreter*’. Lovelace knew the significance of the analytical engine and its implications for computational method. She understood that through the punched card input device, it opened up a whole new opportunity for designing machines that could manipulate symbols rather than just numbers. As she herself observed, ‘*We may say most aptly that the Analytic Engine weaves algebraic patterns.*’ Her achievements are exceptional, given the attitudes of Victorian Britain towards the intellectual pursuits of women. Her translation notes include, in complete detail, a method for calculating a sequence of Bernouilli numbers with the engine, which would have run correctly had the analytical engine been built. This is considered the first algorithm ever specifically tailored for implementation on a computer. Based on this work, Lovelace is now widely credited with being the world’s first computer programmer, and her method is recognized as the world’s first computer program. She died of uterine cancer and excessive blood-letting, aged only 36.

BABBAGE AND THE FUTURE

BABBAGE WAS an inventor, mathematician, scientist, politician, critic of the scientific establishment and a political economist. He pioneered lighthouse signalling, and was the first to propose *black box* recorders for monitoring the conditions preceding railway catastrophes. He advocated decimal currency a century before its introduction, and the use of tidal power once coal reserves were exhausted.

PHOTOGRAPHY

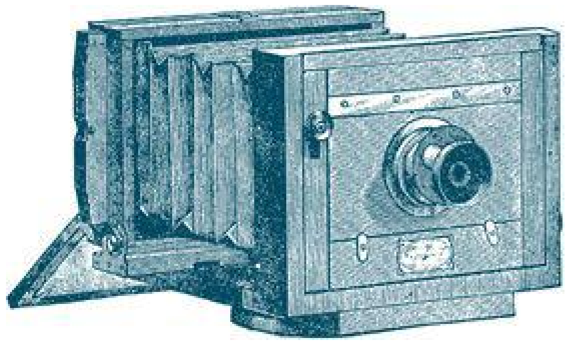
—— 1835 ——

WILLIAM HENRY FOX TALBOT 1800–1877, ENGLAND

Photographs have enabled the visual documentation of historic moments and have captured pleasurable memories for billions of people. Talbot was a Renaissance man who researched and wrote on mathematics, botany, astronomy and archaeology as well as photography This British polymath was inspired by his inability to draw, describing one of his sketches as '*melancholy to behold*'. Talbot wished to fix on paper the fleeting photographic images that had been observed for centuries using a camera obscura, and his invention of the negative/positive process and early developing techniques set the standard for decades. Talbot experimented with the action of light on certain chemicals, in order to capture by other means the view he was unable to draw. With the help of Sir John Herschel, he managed to control this action and *fix* the image, finally producing a negative from which an endless number of positives could be printed. Talbot's process consisted in producing the photographic image on writing-paper highly sensitized by chemical treatment. White images of the objects were formed after a long exposure upon a dark ground, these being the *negatives* from which *positives* could be obtained by printing in the manner still employed. Over the next 30 years, amongst many other things, he worked on photo-mechanical reproduction, creating the photoglyphic engraving process, the forerunner of photogravure.

In September 1840 Talbot greatly improved and accelerated his procedure by employing paper rendered sensitive by iodide of silver and nitrate of silver. This paper received in the first few seconds of its exposure to the light an invisible (latent) image, which could be rendered visible by treating it with a solution of gallic acid. This improved method, at first called the *calotype* and afterwards the *talbotype*, laid the foundation for all subsequent photography until the recent advent of the digital camera. Talbot patented it in 1841 to try to recover some of the costs of his experimentation. In 1851, after the introduction of the *collodion* process of Frederick Scott Archer, Talbot discovered a method by which instantaneous pictures could be taken, and in 1852 he invented a method of photographic engraving. About 1854 he secured a gloss on photographic prints by means of albumen. In 1852, at the request of the presidents of the Royal Society and the Royal Academy, he consented to allow anyone to use his patented processes, with the sole exception of '*portrait-taking for sale to the public*' (i.e. professional studio photographers). Talbot was also a noted

photographer who made major contributions to the development of photography as an artistic medium.



THE ROLE OF FILM

IN 1888 George Eastman’s Kodak camera, which he designed to take his newly invented roll film, popularized photography for the public. In 1889 he also invented a flexible transparent film that led to the beginning of the motion picture industry. Eastman (1854–1932) was a great philanthropist as well as a superb inventor, giving away about $100 million, much of it anonymously. In later life, aged 77, suffering from a degenerative disease of the spine and in constant pain, he shot himself, leaving a suicide note: ‘*My work is done. Why wait?*’

Talbot engaged in photographic experiments beginning in early 1834, well before 1839, when Louis Daguerre exhibited his pictures taken by sunlight. After Daguerre’s discovery was announced (without details), Talbot showed his five-year-old pictures at the Royal Institution on 25 January 1839. The oldest photographic negatives in existence were taken by Talbot in 1835. Within a fortnight, he freely communicated the technical details of his *photogenic drawing* process to the Royal Society. Daguerre would not reveal the details of his process until August 1839. There was a fierce argument between French and English scientists as to who had developed the first camera and printing process. The daguerreotype, although beautiful, was rarely used by photographers after 1860, and had ended as a commercial process by 1865. The French eventually recognized the achievement of Talbot, and at the Paris Exhibition of 1867 awarded him the gold medal.

SCREW MARINE PROPELLER

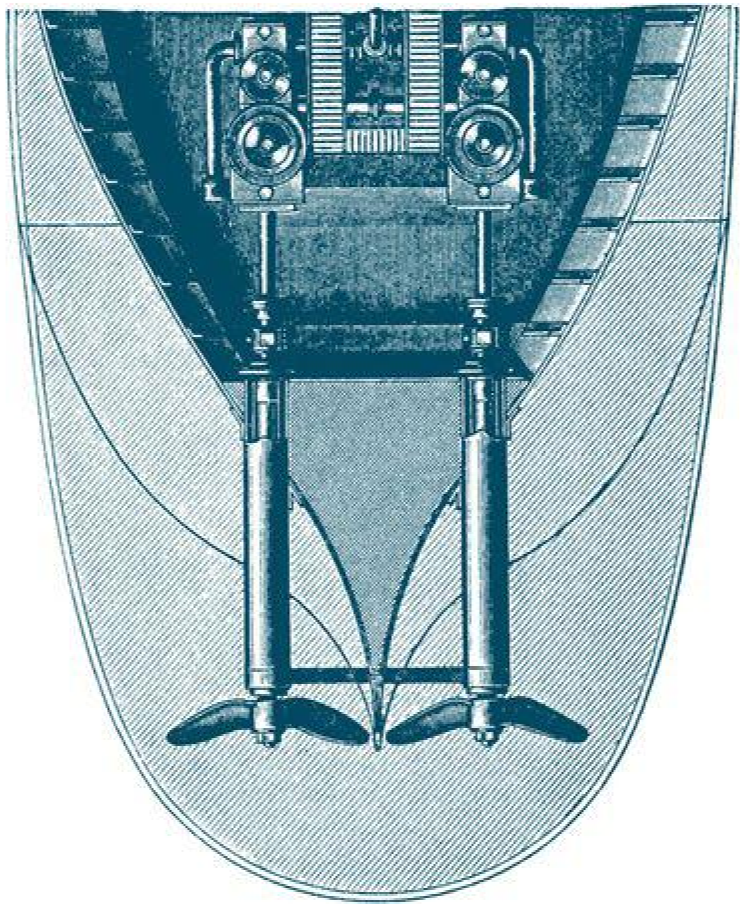
—— 1836 ——

FRANCIS PETTIT SMITH 1808–1874, ENGLAND

The screw propeller is a type of fan that transmits power in ships and turboprop planes by conversion of rotational motion into thrust. Before the end of the 18th century several patents were taken out for screw propellers, and in 1815 Richard Trevithick also took out a patent, but generally ‘Screw’ Smith is given the credit for the invention. He was a farmer who grazed sheep on Romney Marshes in Kent, and his first model was made in 1834, when Smith was 26 years old. The screw in his little boat was worked by a powerful spring. In 1836 he took out a patent for propelling vessels by means of a screw revolving beneath the water at the stern, and in the autumn of that year a small steam vessel with an engine of 6 horsepower was built to test Smith’s invention. The screw was made of wood and had two whole turns. The little vessel was tried on the Thames, and ran well but slowly. As she went up the river the screw struck some floating timber and was broken in half; at this point, to everyone’s amazement, she moved forward more rapidly than before. Smith took advantage of this stroke of luck, and fitted a new screw with only one turn, with which his vessel worked much better. The modern screw propeller with which all ships are fitted is of this one-turn configuration.

In 1839 he built the *Archimedes*, a wooden vessel of 237 tons (240 tonnes) fitted with his patent screw. The builders estimated she could not do more than 5 knots (9.3 kph) but when tested it was found that her speed was no less than 9½ knots. (17.6 kph). In 1840 she made a tour of all the principal ports of Great Britain. After examining the *Archimedes*, the great engineer Brunel redesigned his ship, the *Great Britain*, and fitted it with a screw. The *Great Britain*, built in 1843, was 274 feet (83.5 m) in length, and much the largest steamer that had been launched up to that date. The first British warship to be fitted with a screw was the *Rattler*, of 888 tons (902 tonnes). Tested against the *Alecto*, a paddle ship of similar power, the *Rattler* was far faster. Smith spent all his money trying to get shipbuilders, shipowners and the Royal Navy interested in his invention. In 1856 his patent expired, and he was virtually destitute. However, the Institute of Civil Engineers subscribed £2000 as a testimonial, Queen Victoria granted

him a Civil List pension of £200 a year and he was made curator of the Patent Museum at South Kensington. In 1871, three years before he died, ‘Screw’ Smith was knighted for his work.



TRANSATLANTIC STEAM SHIP AND IRON-HULLED, SCREW PROPELLER-DRIVEN LINER

—– 1837 *and* 1843 —–

ISAMBARD KINGDOM BRUNEL 1806–1859, ENGLAND

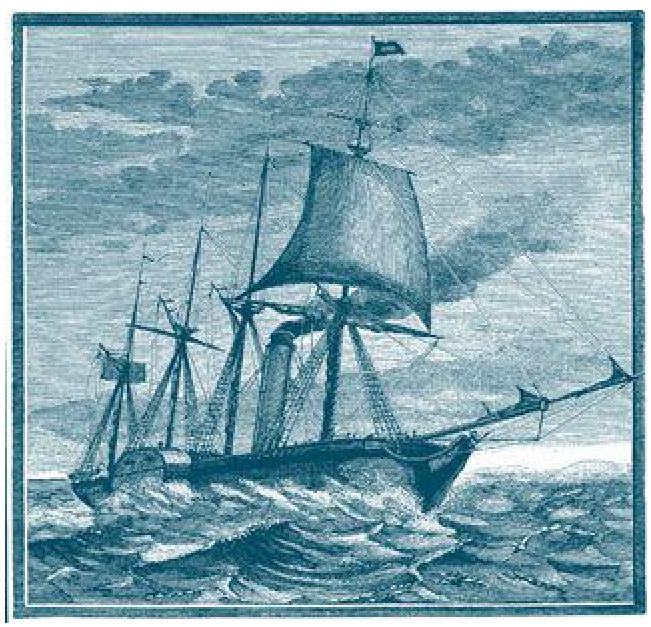
Brunel was a designer and builder of railways, tunnels, bridges, docks and ships, which were copied across the world. Brunel’s first notable achievement was the part he played with his father Marc in planning the Thames Tunnel from Rotherhithe to Wapping. It was completed in 1843. In 1831 Brunel was only 24 when his designs won a competition, and he was appointed project engineer for the superb Grade I-listed Clifton Suspension Bridge across the River Avon in Bristol. Thomas Telford had claimed that

no suspension bridge could exceed the 577-foot (176-m) span of his Menai Suspension Bridge. Construction of the 1352-foot (412-m) span bridge, with a 702-foot (214-m) central span, began the same year, but because of financial difficulties it was not completed until 1864. The longest bridge of its type in the world in its day, around 12,000 cars still cross it every day.

Brunel is probably best remembered for his construction of a network of tunnels, bridges and viaducts for the Great Western Railway. In 1833, he was appointed its chief engineer and work began on the line that linked London to Bristol. Impressive achievements during its construction included the viaducts at Hanwell and Chippenham, the Maidenhead bridge, the Box Tunnel and Bristol Temple Meads Station. Brunel is noted for introducing the broad gauge in place of the standard gauge on this line. While working on the line from Swindon to Gloucester and South Wales he devised the combination of tubular, suspension and truss bridge to cross the Wye at Chepstow. This design was further improved in his famous bridge over the Tamar at Saltash near Plymouth. Brunel was also responsible for the redesign and construction of many of Britain's major docks, including Bristol, Monkwearmouth, Cardiff, Plymouth and Milford Haven.

His steamships *Great Western, Great Britain* and *Great Eastern* set records for their type of construction, speed, power and size. Brunel launched his 236-foot (72-m) SS *Great Western* wooden paddle-wheeler steamship in Bristol in 1837, as an extension of his Great Western Railway. The plan was to carry passengers by train from London to Bristol and then

on to New York by ship. On her maiden voyage to New York in 1838, a race was held with the *Sirius*, which sailed out of Cobh, near Cork. The *Great Western* was demonstrably the quicker vessel (see box on page 206). She was the first steamship to engage in transatlantic service. Brunel's SS *Great Britain* was the world's first oceangoing iron steamer, and the first ship driven by a screw propeller. The largest (302 feet [92 m] long) and most powerful ship in the world, she was launched in 1843, and beat the SS *Great Western's* transatlantic record by a day. She served as a transatlantic liner, an emigrant ship to Australia, a troop carrier in the Crimean War and was converted to a sailing ship and then used for storage in the Falklands. She is now a wonderful museum exhibit in Bristol, where she was built. The SS *Great Eastern*, launched in 1859, was designed in cooperation with John Scott Russell, and was by far the biggest ship ever built up to that time, but was not commercially successful. It was a huge paddle wheeler, 700 feet (213 m) long with five funnels. Her purpose was to serve the England to India route, avoiding coaling several times during the voyage, but she was sold at a loss before she made her maiden voyage. She sailed the Atlantic from 1860–4, and laid transoceanic cables from 1866–74, being broken up in 1888.



FUEL CELL

— 1838 —

WILLIAM ROBERT GROVE 1811–1896, WALES

A Welsh high court judge, Grove became both a fellow of the Royal Society and professor of the London Institution, writing the seminal 19th-century scientific work *Correlation of Physical Forces*. Grove is known as 'the father of the fuel cell', overseeing the genesis of a 'clean' power source. His contribution to battery or cell development was to devise a combination of metals and liquids that greatly reduce the loss of voltage. In the simple early cells, hydrogen bubbles collected at the poles, setting up a back voltage that greatly weakened the current, a phenomenon called *polarization*. To solve the problem, experimenters used liquid *depolarizers* that eliminated the hydrogen by oxidizing it into water, but this resulted in low voltage batteries. Grove experimented and used nitric acid as an oxidizing agent, producing a higher voltage battery. He later described his results to a meeting in Birmingham in 1839. He '*hastily constructed*' a battery for the meeting, placing a zinc (positive) electrode and dilute sulphuric acid in one compartment, and a platinum (negative) electrode and strong nitric acid in another. The compartments were porous pots that allowed the easy passage of the electric current but safely contained the liquids. The resulting battery had a much higher voltage and, with low internal resistance, a stronger current than any previous battery. Instead of harmful gases, *Grove cells* produce water, and they are being used in a new generation of hydrogen-powered cars, backed by US government funding. Fuel cells were used by NASA to power onboard systems for its *Apollo* and *Shuttle* space programmes. James Joule's claim that each of the various manifestations of force and energy in nature is convertible into any other was made originally by Grove in his *Correlation of Physical Forces*.

AROUND THE WORLD IN 80 DAYS

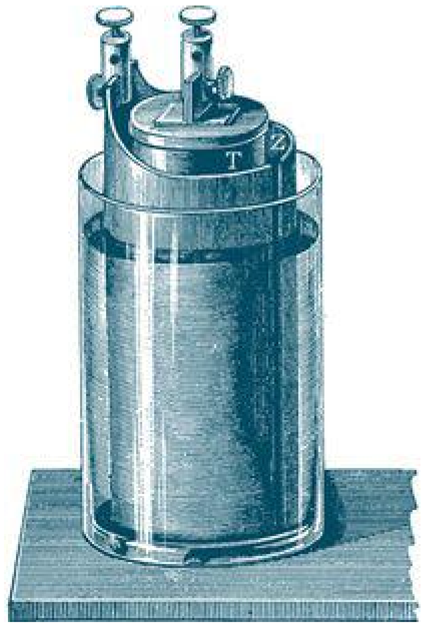
THE RIVAL British and American Company chartered *Sirius* to beat *Great Western* to New York. She was a 700-ton (711-tonne) steam packet on the London–Cork route, and the company removed part of her passenger accommodation to make room for extra coal bunkers for the transatlantic crossing. She left London three days before *Great Western*, refuelling at Cork, and departed for New York on 4 April. *Great Western* was delayed in

Bristol because of a fire and did not depart until 8 April. *Sirius* only narrowly beat *Great Western*, arriving on 22 April. When coal ran low, her crew burned cabin furniture, spare yardarms and one mast, inspiring the similar sequence in Jules Verne's novel *Around the World in Eighty Days*. *Great Western* arrived the following day, with 200 tons (203 tonnes) of coal still aboard. In effect, the Great Western was four days faster, sailing at 8.66 knots (16 kph) compared to 8.03 knots (14.9 kph).

FUEL CELL FUELS

A FUEL cell is an electrochemical cell that converts chemical energy from a fuel into electrical energy. Electricity is generated from the reaction between a fuel supply and an oxidizing agent. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained.

Fuel cells are significantly different from conventional electrochemical cell batteries as they need to consume reactant from an external source, which must be periodically replenished. This is a called thermodynamically open system, whereas conventional batteries store electric energy and are a closed system. The hydrogen fuel cell uses hydrogen as its fuel, and oxygen (usually derived from the air) as its oxidant. Fuels can include alcohols or hydrocarbons and oxidants can include chlorine and the bleaching compound, chlorine dioxide.



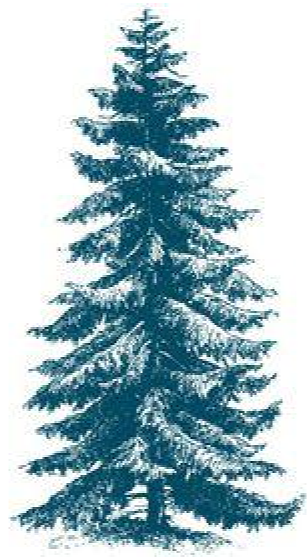
PULPED WOOD PAPER

—— 1838 *or* 1839 ——(1845 *patent*)

CHARLES FENERTY 1821–1892, CANADA, AND FRIEDRICH GOTTLOB KELLER 1816–1895, GERMANY

By using an unlimited supply of wood to make paper, Fenerty and Keller revolutionized communications during the Industrial Revolution, creating a similar effect to today's Internet. Fenerty grew up on his family's large farm in Nova Scotia, which had three sawmills to process its timber. As the public became more literate, there was a huge demand for books and newspapers, but Fenerty saw that papermills could not obtain enough cotton and linen rags to supply this new demand for paper. He felt that paper could be produced from wood, which would be far cheaper because of the availability of huge Canadian and American forests. Fenerty knew that wood was a vegetable fibre, just like cotton and linen, and he experimented with soft spruce as the most suitable wood for conversion into what he termed *pulp paper*. Wasps construct their paper-like nests from chewed wood, and this may have led him to his conclusion. Another theory is that he spent long hours at the sawmills, watching the movement of the heavy wooden frames in which the saws were fixed, as they lifted and fell within a wooden slide. This constant friction of wood rubbing against wood during

the rising and falling motion produced a small quantity of fuzzy waste material.



FRIEDRICH KELLER'S INVENTION

FRIEDRICH GOTTLOB Keller invented the wood pulp process for papermaking around the same time as Fenerty. His wood-cut machine extracted the fibres needed for pulping wood. He was inspired by an article he had read by the French mathematician René de Réaumur, who felt that paper could be made from trees. In 1841 Keller jotted notes in his 'idea-book' about a woodcutting machine to extract fibres for pulped-wood paper making. In 1844 Keller produced a piece of pulped wood paper from his wood-cut machine, but failed to get government support. He wished to develop an improved wood grinder, and sold his invention to a paper specialist, Heinrich Voelter, for the equivalent of £80. A patent was granted to Keller and Voelter in 1845 in Saxony. In 1848 the first machines appeared, but in 1852 when the renewal of the patent was due, Keller did not have the money to renew his part of the patent. Voelter was now the sole patent holder and continued massively profitable production without Keller. Keller's wood-grinding machine was sold throughout Europe and the Americas. It took 20 years for newspaper and book printers to prefer pulped wood to pulped rags, but by the end of the 19th century, wood had become the preferred choice for making paper. Throughout his life, Keller received no royalties from his invention.

FENERTY LETTER

'Messrs. English & Blackadar, Enclosed is a small piece of PAPER, the result of an experiment I have made, in order to ascertain if that useful article might not be manufactured from WOOD. The result has proved that opinion to be correct, for – by the sample which I have sent you, Gentlemen – you will perceive the feasibility of it. The enclosed, which is as firm in its texture as white, and to all appearance as durable as the common wrapping paper made from hemp, cotton, or the ordinary materials of manufacture is ACTUALLY COMPOSED OF SPRUCE WOOD, reduced to a pulp, and subjected to the same treatment as paper is in course of being made, only with this exception, VIZ: my insufficient means of giving it the required pressure. I entertain an opinion that our common forest trees, either hard or soft wood, but more especially the fir, spruce, or poplar, on account of the fibrous quality of their wood, might easily be reduced by a chafing machine, and manufactured into paper of the finest kind. This opinion, Sirs, I think the experiment will justify, and leaving it to be prosecuted further by the scientific, or the curious. I remain, Gentlemen, your obdt. servant,

CHARLES FENERTY.'

The Acadian Recorder, Halifax, Nova Scotia, 26 October 1844

Fenerty may have realized that this waste fibre could be used to make paper if it was flattened and shaped. According to tradition he showed a small sample of his 'pulp paper', produced by a process that he would later describe as *chafing* the wood, to his wife's brother-in-law Charles Hamilton in 1838 or 1839, when Fenerty was 17 or 18. His discovery would thus predate that of German weaver Friedrich Gottlob Keller (see box). Fenerty, however, did not make his findings public until 26 October 1844, when a letter from him was published in the *Acadian Recorder* (see box above). No commercial advantage was taken in Nova Scotia of Fenerty's discovery. Paper is now produced in factories which pulp the wood and then make the pulp into paper in one of two ways. In the thermo-mechanical pulp (TMP) process, the wood is chipped and then put into steam-heated refiners in which the chips are squeezed and mashed into fibres between two steel discs. In the ground-wood process, logs stripped of bark are fed in to

grinders, where they are squashed against rotating stones and made into fibres.

SOLAR CELL

—— 1839 ——

ALEXANDRE-EDMOND BECQUEREL 1820–1891, FRANCE

This physicist studied the solar spectrum, magnetism, electricity, optics, photography and, with his son Henri, luminescence and phosphorescence. Aged just 19, Becquerel discovered the *photovoltaic effect*, the operating principle of the solar cell. Becquerel observed this effect while experimenting with a solid electrode in an electrolyte solution, seeing a voltage develop when light fell upon the electrode. A solar cell is any device that directly converts the energy in light into electrical energy, through the photovoltaic effect. Sunlight is composed of photons which are packets of solar energy. These photons contain different amounts of energy that correspond to the different wavelengths of the solar spectrum. When photons strike a photovoltaic cell, they may be reflected or absorbed, or they may pass right through. The absorbed photons generate electricity. The effect was studied in solids such as selenium in the 1870s by Heinrich Hertz, who later discovered the *photoelectric effect* in 1887. In 1877 W.G. Adams and R.E. Day published a paper on the photovoltaic effect upon selenium. Soon afterwards, selenium photovoltaic cells were converting light to electricity at 1–2 per cent efficiency. As a result, selenium was quickly adopted in the emerging field of photography for use in light-measuring devices. The first genuine solar cell was built around 1883 by Charles Fritts, who used junctions formed by coating a selenium semiconductor with an extremely thin layer of gold, but the energy conversion ratio was only around 1 per cent. The first solar cell based on the outer photoelectric effect was developed by Alexander Stoletov between 1888 and 1891.

In 1941, the more efficient silicon solar cell was invented by American engineer Russell Ohl. In 1954 three American researchers, Gerald Pearson, Calvin Fuller and Daryl Chapin, designed a silicon solar cell capable of 6 per cent energy conversion efficiency with direct sunlight. The three inventors created an array of several strips of silicon (each about the size of

a razorblade), placed them in sunlight, captured the free electrons and turned them into electrical current. They thus created the first solar panels. Bell Laboratories in New York then announced the prototype manufacture of a new solar battery. The first public service trial of the Bell Solar Battery began with a telephone carrier system in Georgia, USA in 1955, and the company went on to develop cells for space activities. Efficiencies have improved and prices dropped, and solar cells (photovoltaic systems) are a growing part of our lives. The simplest systems power many of the small calculators and wrist watches we use every day. More complicated systems can pump water, power communications equipment, and even light our homes and run our household appliances. By 2007 the University of Delaware and the US Department of Energy had developed solar cells of over 40 per cent efficiency.

BICYCLE

—— *c*.1839 ——

KIRKPATRICK MACMILLAN 1812–1878, SCOTLAND

The first device resembling a bicycle was reputedly constructed in France around 1790 by Comte Mede de Sivrac. (Some sources, however, suggest that the count is a fictional character.) It was named a *célérifère*, soon renamed the *vélocifère*. It was a wooden scooter-like device with no pedals or steering, but very skilled riders could steer it by lifting the front wheel and turning it in the direction they wanted to go – like modern ‘wheelies’. A similar contraption, with a steering mechanism attached to the front wheel, was invented Germany in 1816 by German Baron Karl von Drais. It was known as a *Laufmaschine* or ‘running Machine’ but the baron called it a *Draisienne*. It became popularly known as a ‘hobby-horse’, and was

fashionable as a gentleman’s plaything for use in gardens and parks. On both devices, the rider perched on a seat between two wheels, and used their feet to propel the bicycle like a scooter.

Kirkpatrick MacMillan was a young Scottish blacksmith. As a boy in 1824 he had seen a hobby-horse being ridden along a nearby road, and decided to make one for himself. Upon completion, he realized that radical improvement was possible if he could propel it without putting his feet on the ground. Working at his smithy, he completed his new machine in around 1839. MacMillan’s bicycle had a wooden frame and iron-rimmed wooden wheels, the front wheel providing limited steering. The front wheel measured 30 inches (76 cm) in diameter, and the back had a 40-inch (102-cm) wheel attached to pedals via connecting rods. This first pedal bicycle was propelled by a horizontal reciprocating movement of the rider’s feet on the pedals. The machine was extremely heavy and the physical effort required to ride it was considerable. However, MacMillan mastered the art of riding it on rough country roads, and was soon making a 14-mile (22.5-km) journey in less than an hour. MacMillan never thought of patenting his invention or trying to make any money out of it, but others who saw it realized its potential, and soon copies began to appear for sale. Gavin Dalzell of Lesmahagow copied MacMillan’s machine in 1846 and passed on the details to so many people that for more than 50 years he was generally regarded as the inventor of the bicycle. However, MacMillan appears to have been content with work as a blacksmith and never made any attempt to sell it commercially. He stood by while others built versions of his bicycle and sold them for about £7 each, which was then a considerable amount.

The father and son team of Pierre and Ernest Michaux made carriages in Paris when they first assembled a two-wheeled *vélocipède* around 1867, with its cranks and pedals connected to the front wheel. The *vélocipède* ('fast foot') was also nicknamed the '*boneshaker*' thanks to its rough ride caused by its stiff iron frame and wooden wheels wrapped in an iron rim. The design went to the USA with a former Michaux employee named Pierre Lallement who promptly claimed credit for the idea. He said that he had developed the prototype in 1863, and then set out for America. He filed for the first bicycle patent with the US patent office in 1866. By 1870 metalworking had improved to the point at which bicycles began to be constructed entirely of metal, an improvement in both performance and material strength, and bike design began to change accordingly. The pedals were still attached directly to the front wheel but solid rubber tyres, and long spokes on a much larger front wheel, provided a greatly improved ride. Also, the bigger the wheels, the faster one could go, and *Penny Farthings* enjoyed a great popularity in the 1870s and 1880s. These were constructed with a large front wheel of up to 5 feet (1.5 m) in diameter, and a much smaller back wheel. They were also known as *high wheelers*.

THE FIRST BIKE ACCIDENT

KIRKPATRICK MacMillan rode 68 miles (109 km) from Dumfries to Glasgow in June 1842 to gain publicity for his invention. The trip took him two days and he was fined five shillings for causing a slight injury to a small girl who ran across his path. The *Glasgow Argos* newspaper reported the accident: '*Yesterday, a gentleman, belonging to Dumfries-shire, was placed at the Gorbals police bar, charged with riding along the pavement on a velocipede, to the obstruction of the passage, and with having, by so doing, thrown over a child. It appeared, from his statement, that he had on the day previous come all the way from Old Cumnock, a distance of 40 miles, bestriding the velocipede, and that he had performed the journey in the space of five hours. On reaching the Barony of Gorbals, he had gone upon the pavement, and was soon surrounded by a large crowd, attracted by the novelty of the machine. The child who was thrown down had not sustained any injury; and, under the circumstances, the offender was fined only 5 shillings. The velocipede employed in this instance was very ingeniously constructed. It moved on wheels turned* [steered] *with the hand*

by means of a [foot-operated] *crank: but, to make it "progress" appeared to require more labour than will be compensated for by the increase of speed. This invention will not supersede the railways.'* The judge at his hearing asked MacMillan to ride the cycle in a figure of eight pattern, which he did, and the judge was said to have slipped him the money to pay the fine. On his trip home MacMillan raced the stagecoach.

The next stage of bicycle development came with the creation of the *safety bicycle* in 1885. Englishman John Kemp Starley's design featured a rider perched much lower between two wheels of the same size. This was coupled with a sprocket and chain system that drove the bike from the rear wheel. This is the same basic *diamond frame* design still in use in today's bikes. Starley's design was later allied to inflated rubber tyres. Prices dropped because of mass manufacture and roads improved, leading to popular cycle ownership. It is estimated that there are over a billion bicycles in the world with around 450 million in China alone. MacMillan's invention has evolved to become the most classless and popular form of transport in the world. The renowned 19th-century American feminist Susan B. Anthony said in an interview in 1896: '*I think* [the bicycle] *has done more to emancipate women than anything else in the world.*'

SUPERPHOSPHATE FERTILIZER

—— 1842 ——

JOHN BENNET LAWES 1814–1900, ENGLAND

Lawes began the chemical fertilizer (artificial manure) industry, in the process transforming yields of crops and animals across the globe. Lawes laid the foundations of modern scientific agriculture and established the principles of crop nutrition. He had inherited an estate of over 1000 acres (405 ha) and founded a 250-acre (101-ha) experimental farm at Rothamsted in Hertfordshire. Around 1837, he began experimenting on the effects of various manures on plants in pots, and then transferred those experiments to crops in open fields. In 1842 he patented a manure formed by treating phosphates with sulphuric acid, thus initiating the artificial manure industry. In the same year, Lawes started the first factory for the manufacture of artificial fertilizers.

Phosphorous is an essential nutrient and is now a common component of agricultural fertilizers, but it has to be made soluble to become efficient. Superphosphate is produced by the action of concentrated sulphuric acid upon powdered phosphate rock. Superphosphate that is heavy in nitrogen is good for growth, and when heavy in phosphorus it is good for developing plant buds. It improves the texture of the soil, promotes healthy growth, acts as a fungicide when fed to plants through the leaves, helps control nematodes and activates compost to faster decomposition. With the chemist J.H. Gilbert, Lawes carried on experimenting for a further 57 years in raising crops and feeding animals. The main object of their experiments was to measure the effect on crop yields of inorganic and organic fertilizers. Their ‘Classical Field Experiments’ are a valuable experimental resource for today’s scientists. Before his death Lawes set aside the enormous amount of £100,000 for the Rothamsted experimental farm to carry on his work, which it does today.

By the time of Lawes's death, the huge amount of data accumulated from the 'Classical Field Experiments', together with the inherent variability of agricultural field experimentation, led to the need for a sound approach to statistical methods. Rothamsted is now regarded as a birthplace of modern statistical theory and practice. Rothamsted researchers have made many other significant contributions to science over the years, including the discovery and development of pyrethroid insecticides, as well as pioneering contributions in the fields of virology, nematology, soil science and pesticide resistance. In the second half of the 20th century, the development of aerial topdressing allowed superphosphates to be spread economically over large areas, increasing crop yields substantially. According to his obituary in *The Times* of 1 September 1900, '… *Sir John Lawes was one of the greatest benefactors of agriculture – perhaps the greatest – the world has seen. His originality in experimental research and his inflexibility of purpose, coupled with a genius of no ordinary kind, enabled him to discover grand truths which have had a profound influence upon the progress of agriculture* …'

GUANO – THE ORIGINAL SUPERPHOSPHATE

SUPERPHOSPHATE can be formed naturally in large quantities by the build-up of bird faeces, or guano. The most famous mining site is the island of Nauru in the South Pacific, from which much of the *soil* was mined, producing temporary wealth for the inhabitants. The word *guano* originally

came from the Quichua language of the Inca civilization and means ‘the droppings of sea birds’. Seabirds eat and digest fish, and their faeces, along with rotted carcasses, feathers, eggshells and sand is processed by beetles and microbes to make one of nature’s best fertilizers. Bats also produce guano. Their droppings, which contain the remains of insects that have themselves consumed plant matter, are deposited on the floors of caves in massive quantities over the centuries. There are different factors in the relative amounts of nutrients contained in seabird and bat fertilizer, but an average content of guano would be around 15 per cent nitrogen, 9 per cent potassium and 3 per cent phosphorous. The Incas collected guano from the coast of Peru to use for enriching the soil. They treated the guano as a valuable material by restricting access to it, and punishing any disturbance to the birds with death.

Peruvian guano was considered to be the best in the world, leading to a global trade in the commodity. The Peruvian current brings cold water from Antarctica to the Equator along the coast, and the combination of cold water and warm air prevents rain from falling. The islands along the coast are sun-baked, and the virtual drought means that the nitrates in the guano do not evaporate or leach into the rock, so the fertilizer maintains its effectiveness. The US Government recognized the value of guano by passing an act in 1856, which gave protection to any citizen who discovered a source of guano. The discoverer could take possession of unclaimed land that contained guano, and was entitled to exclusive rights to the deposits. This guano could only be removed for the use of the citizens of the United States. When the Spanish navy occupied the Chincha Islands, depriving Peru of lucrative income from guano, a Peruvian-Chilean alliance fought Spain in the Chincha Islands War of 1864–66. By the end of the 19th century, the huge growth in artificial fertilizers had made guano less important.

VULCANIZATION OF RUBBER

—— 1843 ——

THOMAS HANCOCK 1786–1865, ENGLAND

A coachmaker, Hancock became interested in waterproof fabrics to protect the passengers in his coaches. By 1819 he was experimenting with

making rubber solutions. In 1820 Hancock patented fastenings for suspenders, gloves, shoes and stockings, but found himself wasting large amounts of rubber. He invented a machine to shred the waste rubber, a *masticator*. This allowed rubber to be recycled after which it was then reformed into blocks or sheets. The Scottish chemist Charles Macintosh had developed a cloth for a waterproof garment in 1821. He had used rubber dissolved in coal-tar naphtha to cement two pieces of cloth together. In the same year Hancock and Macintosh began working together to make a ‘double-textured’ rainproof fabric, making what came to be known as *macintoshes*. Hancock experimented with rubber solutions and in 1825 patented a process for making artificial leather, using rubber solution, a variety of fibres and the solvents coal oil and turpentine. By 1830 it was clear that Hancock’s leather solution, prepared with his masticated rubber, was better than that Macintosh’s rubber dissolved in coal-tar naphtha.

In his factory, Hancock worked raw rubber with the new machines he had invented. His machines produced a warm mass of homogeneous rubber that could then be shaped and mixed with other materials, and was more easily dissolved than raw rubber. In 1837 Thomas Hancock at last patented his masticator and spreader, probably motivated by Charles Macintosh’s legal challenges when Hancock tried to achieve patents for methods of making waterproof garments. By 1841 Hancock had created a machine that could process up to 200 pounds (91 kg) of rubber at a time. The masticated rubber that he invented was used for pneumatic cushions, mattresses, pillows and

bellows, hose, tubing, solid tyres, shoes, packing and springs, and Hancock became the largest manufacturer of rubber goods in the world. On 21 November 1843, Hancock took out a patent for the vulcanization of rubber using sulphur, eight weeks before Charles Goodyear in the United States. Named after the Roman god of fire, *vulcanization* makes rubber less sticky and confers superior mechanical properties, allowing the more efficient manufacture of tyres, hoses and the soles of shoes. Hancock's invention and the subsequent development of the rubber industry greatly influenced the development of road transport.

HYPODERMIC SYRINGE

—— 1844 ——

FRANCIS RYND 1801–1861, IRELAND

Until Rynd's invention, it was impossible to inject drugs intravenously (through skin and into a vein). Syringe devices had been in use since the early tenth century, when Egyptian surgeons such as al-Mawsili used a glass suction tube to remove cataracts from a patient. However, the first hypodermic syringes with needles fine enough to pierce skin did not appear until the 1840s. The Irish physician Francis Rynd used the first syringe to inject a sedative to treat neuralgia, revolutionizing medicine with a single push of a plunger. In May 1844 he developed a drip needle for introducing drugs into a vein, again trying to cure neuralgia. Up to that time, it had not been considered possible to administer drugs through the skin, and for the most part drugs could only be given orally. In 1845 Dr Rynd published an article reporting how he had successfully used a hypodermic syringe, writing *'The subcutaneous introduction of fluids, for the relief of neuralgia, was first practised in this country by me, in the Meath Hospital, in the month of May, 1844. The cases were published in the "Dublin Medical Press" of March 12, 1845. Since then, I have treated very many cases, and used many kinds of fluids and solutions, with variable success. The fluid I have found most beneficial is a solution of morphia in creosote, ten grains of the former to one drachm of the latter.'* This was before Alexander Wood, who has often mistakenly been credited with inventing the first hypodermic syringe in 1853. Syringes are now generally disposable with a world market of over 15 billion a year.

CAUSE OF CHOLERA

—— 1849 ——

DR JOHN SNOW 1813–1858, ENGLAND

Snow was a pioneer in the adoption of anaesthesia, medical hygiene and epidemiology. He was one of nine children born into a labourer's family in York. At 14 Snow was apprenticed to a surgeon, 11 years later became a member of the Royal College of Surgeons in 1838, and was admitted to the Royal College of Physicians in 1850. In his era it was assumed that the killer disease cholera was airborne. However, Snow did not accept this *miasma* (bad air) theory, and argued that cholera entered the body through the mouth. He published his ideas in an essay *'On the Mode of Communication of Cholera'* in 1849. He was able to prove his theory in dramatic circumstances in August 1854. A cholera outbreak occurred in London's Soho region, and Snow carefully plotted cases of cholera on a map of the area. He was thus able to identify a public water pump in Broad (now Broadwick) Street as the source of the disease. His studies of the pattern of the disease were convincing enough to persuade the local council to disable the well pump by removing its handle. Although this action has been commonly reported as ending the outbreak, the epidemic may have already been in rapid decline, as explained by Snow himself: *'There is no doubt that the mortality was much diminished, as I said before, by the flight of the population, which commenced soon after the outbreak; but the attacks had so far diminished before the use of the water was stopped, that it is impossible to decide whether the well still contained the cholera poison in an active state, or whether, from some cause, the water had become free from it.'*

SNOW'S OTHER LIFE

JOHN SNOW was one of the first physicians to study and calculate dosages for the use of ether and chloroform as surgical anaesthetics. He published an article on ether in 1847 entitled *'On the Inhalation of the Vapour of Ether'*. A longer work was published posthumously in 1858 entitled *'On Chloroform and Other Anaesthetics, and Their Action and Administration'*. By testing the effects of controlled doses of ether and chloroform on

animals and on humans, he made those drugs safer and more effective. In April 1853 he was responsible for giving chloroform to Queen Victoria at the birth of her son Leopold, and he performed the same task in April 1857 when her daughter Beatrice was born, leading to wider public acceptance of obstetric anaesthesia.

IN SNOW'S OWN WORDS

'On proceeding to the spot, I found that nearly all the deaths had taken place within a short distance of the [Broad Street] *pump. There were only ten deaths in houses situated decidedly nearer to another street-pump. In five of these cases the families of the deceased persons informed me that they always sent to the pump in Broad Street, as they preferred the water to that of the pumps which were nearer. In three other cases, the deceased were children who went to school near the pump in Broad Street … With regard to the deaths occurring in the locality belonging to the pump, there were 61 instances in which I was informed that the deceased persons used to drink the pump water from Broad Street, either constantly or occasionally … The result of the inquiry, then, is that there has been no particular outbreak or prevalence of cholera in this part of London except among the persons who were in the habit of drinking the water of the above-mentioned pump well.'* Letter to the editor of the *Medical Times and Gazette*, 23 September 1854

In 1855 a second edition was published of his cholera essay, with a much more elaborate investigation of the effect of the water-supply in Soho. He showed that the Southwark and Vauxhall Waterworks Company was taking water from sewage-polluted sections of the Thames. Snow's study was a major event in the history of public health, and can be regarded as the founding event of the science of epidemiology. It was also discovered later that this public well had been dug only 3 feet (90 cm) from an old cesspit, which had begun to leak faecal bacteria. The nappies of a baby who had contracted cholera from another source were washed in this cesspit, and so the epidemic started. It was common at the time to have a cesspit under homes. Most families tried to have their raw sewage collected and dumped in the Thames, by *night soil workers*, to prevent their cesspit from filling faster than the sewage could decompose into the soil. However, Snow's

theory of how the disease was transmitted was not widely accepted until the 1860s. In 1857 he had made another contribution to epidemiology in a little-known article in *The Lancet: 'On the adulteration of bread* [with alum] *as a cause of rickets*'. Rickets is a softening of the bones in young people caused by lack of Vitamin D and trace elements. The *germ theory of disease* was not known until 1861, so Snow was unaware at the time of the mechanism by which diseases were transmitted.

CHOLERA DEATHS

CHOLERA IS an acute intestinal infection caused by ingestion of food or water contaminated with the bacterium *Vibrio cholerae*. It has a short incubation period, between one and five days, and produces an enterotoxin that causes a copious, painless, watery diarrhoea that can quickly lead to severe dehydration and death, if treatment is not promptly given. Vomiting also occurs in most patients. Cholera remains a global threat and is one of the key indicators of social development. While the disease no longer poses a threat to countries with minimum standards of hygiene, it remains a

challenge in countries where access to safe drinking water and adequate sanitation cannot be guaranteed. Almost every developing country suffers cholera outbreaks, or the threat of a cholera epidemic. Worldwide, cholera affects 3–5 million people and causes 100,000–130,000 deaths a year as of 2010.

TOOTHPASTE – AND ITS COLLAPSIBLE TUBE

—— 1837 *and* 1892 ——

DR WASHINGTON WENTWORTH SHEFFIELD 1827–1897, AND DR LUCIUS TRACY SHEFFIELD 1854–1911, UNITED STATES

Toothpaste promotes oral hygiene, acting as an abrasive to remove dental plaque and food from the teeth, and suppressing halitosis (bad breath). Active ingredients such as calcium, fluoride and xylitol are now included to help prevent tooth decay and gingivitis (gum disease). However, most of the cleaning is done by the mechanical action of the toothbrush, and not by the toothpaste. Salt and baking soda can be substituted for commercial toothpaste. As long ago as 5000 BCE the Egyptians were making a tooth powder consisting of the powdered ashes of ox hooves, myrrh, powdered and burnt eggshells and pumice. Toothpaste was used in 500 BCE in both China and India. The Greeks, and then the Romans, improved the recipes for toothpaste by adding abrasives such as crushed bones and oyster shells, which were used to clean debris from teeth. The Romans later added powdered charcoal and more flavouring agents to improve the breath.

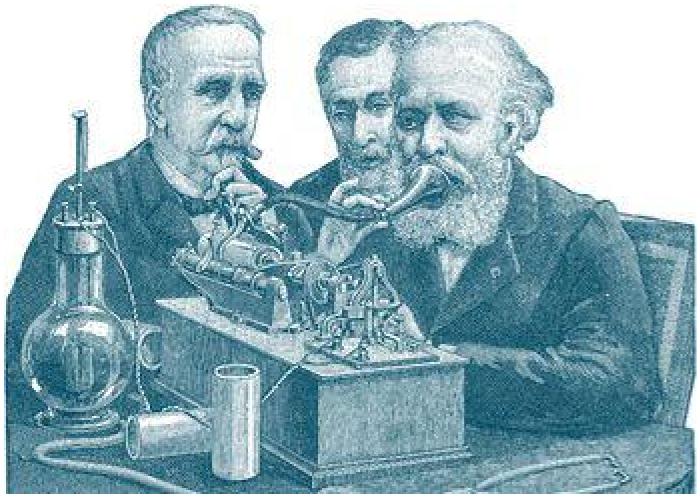
Modern toothpastes were developed in the 1800s. In 1824 a dentist named Peabody was the first person to add soap to toothpaste. John Harris added chalk as an ingredient to toothpaste in the 1850s. In 1850, Dr Washington Sheffield, a dental surgeon and chemist, invented the first ‘modern’ toothpaste in New London, Connecticut. Dr Sheffield had been actively recommending his invention, which he called *Dr. Sheffield’s Creme Dentifrice*. The positive response of his patients encouraged him to market the paste in jars. He constructed a laboratory to improve his invention, and built a small factory to manufacture it. The collapsible metal tube was patented in 1841 by John Goffe Rand, an American artist living in England, as a handy way of storing his paints and inks. Washington Sheffield’s son Lucius studied in Paris for two years and saw French painters using the

paint tubes, so adapted the idea for toothpaste in 1892. (Dr Lucius Tracy Sheffield also took out a patent for a razor strop in 1893.) Sheffield’s company was to become Colgate. In 1896, Colgate Dental Cream was packaged in collapsible tubes, the original tubes being made of lead. Its advertising slogan was ‘*Comes out a ribbon, lies flat on the brush*’. However, pre-mixed toothpastes did not surpass the popularity of tooth powder until the First World War.

Advances in the development and production of synthetic detergents made after the Second World War allowed for the replacement of the soap used in toothpaste with emulsifying agents. In 1955 Procter & Gamble’s *Crest* was the first fluoride-containing toothpaste clinically proven to prevent oral decay. In 2006 the first toothpaste appeared in Europe containing synthetic hydroxylapatite as an alternative to fluoride, for the re-mineralization and protection of tooth enamel. It protects the teeth by creating a new layer of synthetic enamel around the tooth, instead of hardening the existing layer with fluoride that chemically changes it into fluorapatite.

HOW THEY MAKE STRIPED TOOTHPASTE

THE TUBE is filled with white toothpaste, to a certain level. Above that level, the tube is filled with the red ‘stripe’ ingredient. Both materials are viscous enough so that they don’t mix. The trick is to eject these two substances from the tube in separate ways, but at the same time. The toothpaste nozzle is not just a hole at the top of the tube. Instead, it is a longish pipe reaching down the tube, and just ending at the filling level of the carrier material (the white toothpaste). The pipe has small holes in it, further up and closer to the nozzle. Pressing the tube will cause the carrier material to enter the outlet pipe and press the stripe material. The stripe will enter the outlet pipe through the small holes, which is where the stripes are laid onto the toothpaste as it emerges from the tube.



CHAPTER 6

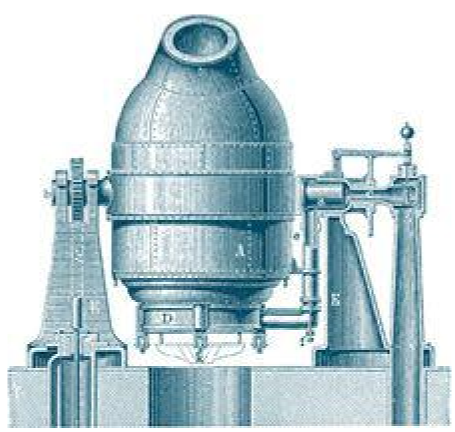
NEW INDUSTRIAL TECHNOLOGY

MASS PRODUCTION OF STEEL

—— 1855 (*patent*) ——

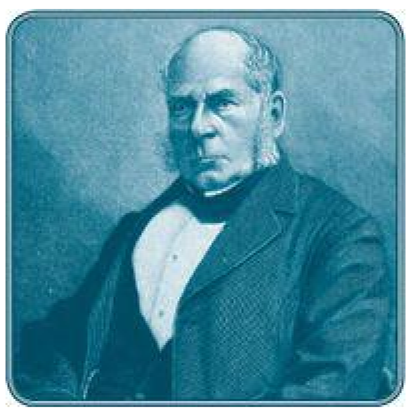
HENRY BESSEMER 1813–1898, ENGLAND

Steel is one of the most common materials in the world, with more than 1.3 billion tons produced annually. It is a major component in buildings, infrastructure, tools, ships, cables, cars, machines, appliances and weapons. While blast furnaces produced cast iron with great efficiency, the process of refining cast iron into the far more useful malleable wrought iron remained comparatively inefficient. (It was called ‘wrought iron’ because it had been usually worked, or wrought, by hand). Demand for wrought iron reached its peak in the 1860s with the building of railways and adaptation of ironclad warships, but then declined drastically as cheaper mild (low carbon) steel became available. Steel had been extremely expensive, having been produced by various inefficient methods long before the Renaissance, but its use had become more common after more efficient production methods were devised in the 17th century. In 1850 great economy in blast furnace practice was achieved at the Ebbw Vale ironworks. Its chemist, George Parry, was the first person successfully to adopt the cup and cone on blast furnaces, which was then copied across Europe. With the patented invention of the ‘Bessemer process’ in 1855, steel soon became an inexpensive mass-produced material, made from molten pig-iron.



AFRICAN STEEL FROM THE TIME OF CHRIST

THE HAYA people of Tanzania discovered a type of high-heat blast furnace, which allowed them to forge carbon steel at 3276° F (1802° C) nearly 2000 years ago. This ability to produce high quality steel was not duplicated until centuries later in Europe during the Industrial Revolution. This discovery was made accidentally while anthropologist Peter Schmidt was learning about the history of the Haya via their oral tradition. He was led to a tree which was said to rest on the spot of an ancestral furnace used to forge steel. He then asked a group of elders to recreate the forge. They were the only ones to remember the practice, which had fallen into disuse due in part to the abundance of steel imported into the country. In spite of their lack of practice, the elders created a furnace using mud and grass, which when burned provided the carbon needed to transform iron into steel. Later investigation of the local area yielded 13 other furnaces similar in design to their recreation. The process is very similar to open hearth furnace steelmaking, and the furnaces were carbon dated and were found to be as old as 2000 years.



The process had been independently discovered in 1851 in the USA by William Kelly (1811–1888), but bankruptcy forced Kelly to sell his patent to Henry Bessemer, who was working along similar lines. Henry Bessemer also paid the Ebbw Vale Company £30,000 for their patents on steel making. George Parry received £10,000 for his steel-making process, which was similar to Kelly’s. The key principle is to remove impurities from the iron by oxidation, with air being blown through the molten iron. The oxidation also raises the temperature of the iron mass and keeps it molten. The process using a basic refractory lining is now known as the *basic Bessemer process* or *Gilchrist-Thomas process* after the discoverer Sidney

Gilchrist Thomas. Parry's steel process in turn had been purchased in 1855 from the American J.G Martien, and improved. Thus the 'Bessemer process' was invented by Martien, Parry and Thomas, not solely by Bessemer who innovated it. Further refinements such as *BOS* (basic oxygen steelmaking) lowered the cost of production while increasing quality.

PRINTING TELEGRAPH SYSTEM (TELEPRINTER)

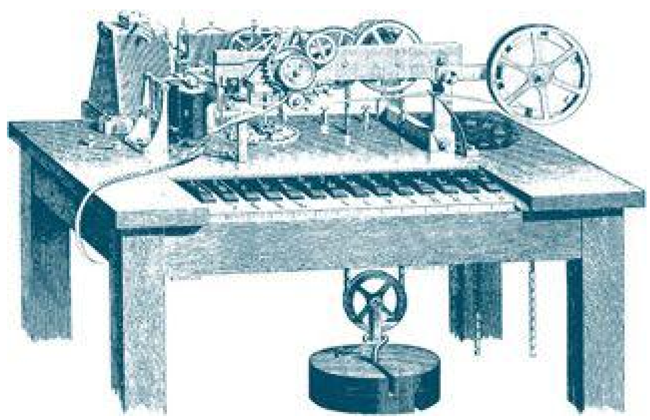
—— 1856–1859 ——

DAVID EDWARD HUGHES 1831–1900, WALES AND UNITED STATES

Hughes made the original breakthroughs in telephony, broadcasting, telegraphy and powder coating. Apart from his successful teleprinter and telegraph system of 1856–9, Hughes invented the carbon microphone vital to telephony and broadcasting in 1877. He invented the induction balance (1878), the metal detector (1878), the world's first radio wave transmission (1879) and the technology of powder coating (1879). A virtuoso pianist, at the age of 19 he held both the professorships of music and natural philosophy at St Joseph's College, Bardstown, Kentucky. (Though born in Wales, Hughes's family had emigrated to the USA when he was seven.) Hughes invented the printing telegraph when he was just 23. His keyboard enabled the corresponding letter to be printed at a distant receiver, working a little like the golfball typewriter before any typewriter was invented. Hughes's mechanism became the genesis of the modern teleprinter, telex system and even the computer keyboard is its direct descendant. This was patented in 1856, and it caused several small telegraph companies to merge and form Western Union Telegraph Co. so as to exploit telegraphy across the USA using the *Hughes System*. His system was thought to be better, and much cheaper, than the monopoly enjoyed by American Telegraph's Morse system.

Hughes received US patents for the *Telegraph* (with alphabetic keyboard and printer) in 1856, the *Duplex Telegraph* in 1859 and the *Printing Telegraph* (with type-wheel) also in 1859. Hughes returned to Europe, where his telegraph system became the accepted standard after Hughes had travelled around Europe, implementing his system. He became one of the most highly decorated scientists of the period, honoured by most European nations. Charles Wheatstone in 1827 had been the first to use the term

microphone, and Hughes revived it in 1878 for the name of his new invention. He discovered that a loose contact in a circuit containing a battery and telephone receiver would give rise to sounds in the receiver, which corresponded to the vibrations impinged upon the diaphragm of the mouthpiece or transmitter. Hughes's invention of the *loosecontact* carbon microphone in 1877 made practical telephony a possibility for the first time. Hughes revealed his secrets to the Royal Society at London on 8 May 1878, and to the general public in June of the same year. This invention was vital to telephony and later to broadcasting and sound recording. Hughes refused to take out patents, but gifted the invention to the world.



Also in 1878 he invented the induction balance, then known as *Hughes' Induction Balance*, to detect concealed metal, such as the position of bullets in a wounded person. It forms the basis of today's metal detectors. In 1879 he held an experiment in Great Portland Street in London. At one end of the street Hughes had a spark transmitter to generate electromagnetic waves, and at the other a *coherer*, a piece of equipment to receive the waves. He had proposed the theory to James Clerk Maxwell, and the president and secretary of the Royal Society witnessed the success of the experiment. Hughes had demonstrated the first radio transmitter and receiver in the world, and thereby proved the existence of electromagnetic radiation. The committee was not impressed, however, and attributed the effects to Faraday induction rather than electromagnetic radiation. Hughes even developed a radio system to transmit signals several miles across the Bristol Channel from Wales to England. Hughes was thus the first person in the world to transmit and receive radio waves, eight years before Hertz, and was the real inventor of the wireless radio, rather than Marconi who knew

Hughes and his work well. In 1879, Hughes discovered that when a stick of wood covered with powdered copper was placed in an electrical circuit, the copper would adhere when a spark was made. This discovery developed into the invaluable technology of *powder coating* of metals. His research into the experimental theory of magnetism was a major contribution to electrical science. His telegraph was internationally used until the 1930s, and his microphone is the forerunner of all the carbon microphones now in use.

METAL-CASED CARTRIDGE AND CARTRIDGE REVOLVER

—— 1857 ——

DANIEL BAIRD WESSON 1825–1906, AND HORACE SMITH 1808–1893, UNITED STATES

The introduction of the self-contained bullet and powder-filled cartridge was an important step in the evolution of the gun. For nearly two centuries, the muzzle-loading flintlock had been the staple firearm, but towards the end of the 18th century it was replaced by the percussion lock, which represented a significant improvement in efficiency. This advance in weapons technology also made possible the multiple-shot revolver, and in 1837 Samuel Colt invented the world's first such handgun. Having been a sailor, Colt applied the mechanism that raised a ship's anchor to the rotating cylinder of his revolver. In 1847, following the advice of Sam Walker of the Texas Rangers, Colt produced the *Walker Colt*, a huge 0.44 calibre gun. With this sudden advancement in weaponry, paper cartridges were developed. During the American Civil War, paper cartridges, which comprised measured amounts of powder, wad and ball, were regularly issued to the military. Soldiers would bite off the ends of the paper, and pour the contents into the barrels of their weapons, and then pack the contents down. Cartridges were also produced which were made of paper which had been soaked in nitrate, making the paper highly combustible. The entire cartridge could be packed into a gun and then fired. This significantly cut down the time needed to reload. However, it also made the contents of ammunition pouches highly combustible and susceptible to disastrous explosions. There were also occasions when the cartridge would not fire, leaving a soldier with the contents rammed in his weapon.

In 1857 the Smith & Wesson Company produced the world’s first metallic-cartridge, breech-loading revolver. This was a huge breakthrough in firearms technology. No longer was it necessary to pack powder, wads and balls, and then install percussion caps to ignite the powder. Everything was in one package and needed only to be inserted into a gun. A former Colt employee, Rollin White, had patented a revolver design with cylinders bored end-to-end. He had approached Sam Colt with his new rear-loading cylinder design that would accommodate metallic cartridges, but Colt felt that the cap and ball revolver would never be replaced. Daniel Wesson heard of White’s design, and in 1856 a meeting was set up with Rollin White in which they agreed upon an arrangement giving Smith & Wesson the exclusive licence to manufacture bored-through cylinders. The *Smith & Wesson Model One* of 1857 was the first firearm manufactured by Smith and Wesson, and the first commercially available revolver to use rimfire cartridges instead of loose powder, musket ball and percussion caps. It was a single-action, tip-up revolver holding seven 0.22 cartridges. Its success was due to a combination of new innovations, the bored-through cylinder and the self-contained metallic cartridge. At the outbreak of the Civil War, the *Smith & Wesson Model Two* 0.32 calibre revolver was in such great demand that at one point the company was forced to stop taking new orders as they could not manufacture enough to keep pace.

CARTRIDGE PAPER

THE ORIGINAL cartridge for military arms dates from 1586. It consisted of a charge of powder and a bullet in a tube made of thick paper. Thick writing and wrapping paper is still known as *cartridge paper* from its use in these cartridges.

DO YOU FEEL LUCKY?

SMITH & WESSON'S revolvers and pistols have become standard issue to police and armed forces throughout the world. They have been featured in numerous Hollywood movies, particularly in Clint Eastwood's *Dirty Harry*, where he carries a six-shot, double action Model 29 0.44 Magnum. It had been primarily the province of handgun enthusiasts, some law enforcement personnel and hunters until 1971, when the actor made it famous. After the film's release retailers had trouble keeping the Model 29 in stock. Eastwood's character, Harry Callahan, says: '*I know what you're thinking. "Did he fire six shots or only five?" Well, to tell you the truth, in all this excitement I kind of lost track myself. But being as this is a .44 Magnum, the most powerful handgun in the world, and would blow your head clean off, you've got to ask yourself one question: "Do I feel lucky?" Well, do ya, punk?*'

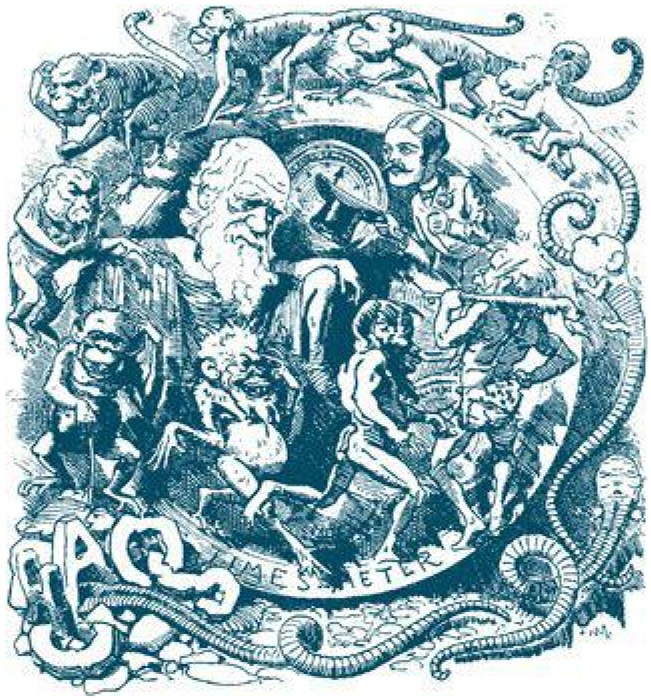
In 1870 Smith & Wesson's patent ran out, and Colt immediately began converting its cap and ball revolvers to cartridge guns. Two employees obtained a patent on the means by which a cap and ball revolver could be converted to fire cartridges. The rear end of the cylinder was sawn off and the holes machined to accommodate cartridges. A loading gate was added behind the cylinder, the powder-packing lever was removed, the recess plugged, and a shell ejector added to the side of the barrel. The US Army submitted their weapons for conversion. In 1870 a customer could mail his 'black powder' revolver to the Colt Factory and, for $5, have it converted. In 1871 Colt produced its first dedicated cartridge revolver. It was essentially a modified 'black powder' revolver with the distinctive open top. In 1873 Colt introduced the 0.45 calibre *Single Action Army* revolver, the famous *Peacemaker*, the Colt 45. When Wild Bill Hickok was murdered while playing poker in 1876 in Deadwood, holding what has since become known as the *Dead Man's Hand* of aces and eights, he was carrying a Smith & Wesson 0.32 calibre revolver. Today's handguns essentially use the same technology as those invented by Smith, Wesson and White.

ORIGIN OF THE SPECIES

— 1858 —

ALFRED RUSSEL WALLACE 1823–1913, WALES

Wallace was the first to propose a theory of evolution due to natural selection, which prompted Charles Darwin to publish *On the Origin of the Species* in 1859. In 1858 Wallace was a young scientist working in the Pacific, and he sent an academic paper to Charles Darwin (1809–1882) on the tendency of varieties of species to depart from the original type. Darwin quickly used its context to present it as a joint paper while Wallace was still abroad, thereby making Darwin's name with the greatest single discovery in the life sciences. Wallace was honoured to be associated with the older, more famous naturalist, knowing that Darwin's approval would help him to fund more research travels. Darwin immediately used Wallace's theory as the framework for his own research of the previous 30 years. Wallace is now almost forgotten, while Darwin and the *Origin of the Species* are known the world over. In the 1840s Wallace had been employed redrawing property boundaries as common land was enclosed and the rich squirearchy divided up the land – he later called this '*a legalised robbery of the poor*'. From 1848 to 1852 Wallace explored South America, but his ship sank on the voyage home, and all his precious specimens were lost (except for those he had sent home earlier). He was in the Malay Archipelago from 1854 to 1862, collecting 125,000 specimens, and in 1869–70 worked in Borneo. In Adrian Desmond's and James Moore's biography, *Darwin* (1997), we see Wallace as a '*self-taught socialist*' who '*saw humanity as part of a progressive world governed by natural law*' and who '*had learned to see morality as a cultural product*'. Wallace adapted Malthusian logic on the over-population of mankind to the animal kingdom. He regarded natives such as the Dyaks in Borneo with admiration for their adaptation to their environment. (On the other hand, the independently wealthy Darwin was disgusted on his travels by the natives of Tierra del Fuego.) Thus Wallace developed a far more rounded theory of selection and evolution, in that one had to adapt and that the environment extinguished the unfit, rather than Darwin's '*competition between species*'.



During the period 1848–70 Wallace was researching and collecting overseas for all but eight years, with little opportunity of competing with Darwin’s prestige amongst the scientific community at home. Darwin only spent five years overseas, upon the *Beagle* between 1831 and 1836, as a self-funded ‘gentleman naturalist’, whereas Wallace was living rough in jungles and swamps. Sir Richard Owen (1804–1892) was an associate of Darwin, and in his 1849 *On the Nature of Limbs* had suggested that humans ultimately evolved from fish as the result of natural laws. Robert Chambers (1802–1871) in 1844 published anonymously *Vestiges of the Natural History of Creation* arguing the case for evolution, along the lines suggested by Jean-Baptiste Lamarck’s (1744–1829) cohesive theory of a ladder of evolution towards more complex species. Other claimants to the discovery of evolution are Dr James Hutton in 1785, William Smith in 1796 and Baron Cuvier in 1812. Everything was in place for Darwin to write his theory, or even simply to modify Lamarck’s work, but it took Wallace’s letter to sting him into action, 22 years after his voyage of discovery.

THE WALLACE LINE

THE *Wallace Line* between the islands of Bali and Lombok, and between Borneo and the Celebes, showed the first biogeographers the division

between flora and fauna in similar climates. West of the line are found organisms related to Asiatic species; to the east, a mixture of species of Asian and Australian origin are present. Wallace had spent four years in the Amazon basin, and another eight years collecting specimens in the Malay Archipelago, travelling widely among the hundreds of islands that make up modern Indonesia.

In David Quammen's *The Song of the Dodo* (1996) we see Darwin's 'Watergate' moment where some of his lies are documented. Crucial letters went '*missing*' and '*somebody cleaned up the file*' to give the great man credit for Wallace's work. '*And Wallace was to post the question dismissed by Darwin – what was the purpose of natural selection? Evolutionary forces worked towards a just society, this was the point – "to realise the ideal of perfect man." Darwin accepted nothing so utopian.*' Wallace's books included *A Narrative of Travels on the Amazon and Rio Negro* (1853), *On the Law Which Has Regulated the Introduction of New Species* (1855), *The Malay Archipelago* (1869) and *Contributions to the Theory of Natural Selection* (1870). He also pioneered 'zoogeography' with his 1876 *Geographical Distribution of Animals*. Wallace was before his time – a socialist, he campaigned strongly for women's suffrage, receiving criticism from the academic community for this, and also proposed the nationalization of land. A naturalist, geographer, anthropologist and biologist, he has been called 'the father of biogeography', and is a precursor of the science of ecology.

ELECTRIC LIGHT BULB

—— 1860 ——

JOSEPH WILSON SWAN 1828–1914, ENGLAND

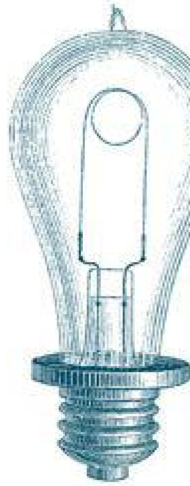
In 1860 Joseph Swan developed a primitive electric light bulb, using a filament of carbonized paper in an evacuated glass bulb. However, the lack of good vacuum and an adequate source of elctricity meant the bulb only enjoyed a short lifetime, and gave off an inefficient light. In 1875 Swan returned to work on the light bulb, with the aid of new and better vacuum techniques and a carbonized thread as a filament. There was a little residual oxygen in the vacuum tube to ignite the filament, allowing the filament to

glow almost white-hot without catching fire. However, the filament had low resistance, so needed heavy copper wires to supply it. Swan received a British patent for his incandescent light bulb in 1878. In the United States, Thomas Alva Edison (1837–1941) had been working on copies of the original light bulb patented by Swan, trying to make them more efficient.

SWAN AND PHOTOGRAPHIC FILM, 1879

SWAN ALSO invented a dry photographic process. While he was working with wet photographic plates he noticed that heat increased the sensitivity of the silver bromide emulsion. By 1871 he had found a method of drying the wet plates, initiating the age of convenience in photography. Eight years later Swan patented bromide paper, the paper commonly used in modern photographic prints. This invention led to a huge improvement in photography and progress towards the development of modern photographic film.

Edison now obtained patents in America for a copy of the improved Swan light, starting an advertising campaign which claimed that he was the real inventor. Swan was less interested than Edison in making money from the invention. To save on litigation costs, he agreed that Edison could sell the lights in the USA (incidentally making a fortune with which to pursue other projects), while Swan retained the rights in Britain. Still searching for a better filament for his light bulb, in 1881 Swan developed and patented a process for squeezing nitrocellulose through holes to form conducting fibres. His Swan Electric Lamp Company switched to using these cellulose filaments (Edison used bamboo) in its bulbs. After Edison and Swan merged to become Ediswan, American lamps also used cellulose. The textile industry also used Swan's process to form fibres. Swan's house in Gateshead was the first in the world to be lit entirely by light bulbs, and the Lit and Phil lecture theatre in nearby Newcastle was the first public building to be lit by electric light, during a lecture by Swan on 20 October 1880. In 1881, London's Savoy Theatre was lit by Swan incandescent lightbulbs, becoming the first theatre, and the first public building in the world, to be artificially lit entirely by electricity.



THE FIRST ROOM IN THE WORLD LIT BY ELECTRICITY

IN 1878 the world's first hydroelectric power station supplied electricity to arc lamps in the gallery of Cragside House, the mansion of Sir William Armstrong in Northumberland. The lamps were replaced in 1880 by Joseph Swan's incandescent lamps in what Swan considered to be '*the first proper installation*' of electric lighting. At this time there was no on-off switch. To turn the lamps off, their copper bases had to be lifted out of mercury baths that helped transmit the current. The four lamps are still in situ in the gallery.

MAIL ORDER

—— 1861 ——

PRYCE PRYCE-JONES 1834–1920, NEWTOWN, WALES

Pryce-Jones worked from the age of 12 to 21 at a draper's business, and then opened his own small shop selling drapery in Wales. Newtown was a centre of the Welsh woollen industry and local Welsh flannel formed the mainstay of his business. Flannel is a soft woven fabric, originally made from carded wool, and was invented in Wales in the 16th century. The advent of a national postal service from 1840, and the arrival of railways in Newtown from 1859, helped Pryce-Jones turn his shop into a global company. He decided to send out promotional leaflets, from which people

could choose what they wanted, and Pryce-Jones would then despatch the goods by post and train. It seems that he had the idea from his knowledge of the rural community. Farmers and their labourers did not have time to travel by horse to a shop on a working day, and on their one day off, Sundays, shops had to be closed. This was the world's first mail order business, and it was to change the nature of retailing. Expansion of the railways allowed Pryce Jones to take orders from further afield and his business grew rapidly. During the 1870s Pryce Jones took part in exhibitions all over the world, winning several medals and becoming world famous.

By the 1880s his patrons included the royal houses of Austria, Britain, Denmark, Germany, Hanover, Italy, Naples and Russia. In 1862 he received an order from Florence Nightingale, and promptly used her name in his advertising material. Pryce-Jones trumpeted his famous customers on his leaflets, which developed into bigger and bigger catalogues, selling house wares and clothes and well as draperies. He began selling Welsh flannel from Newtown to America, Australia and India, and several times had to relocate to larger premises. In 1879 he built the Royal Welsh Warehouse, a tall redbrick building in the centre of Newtown which still stands today. By 1880, he had more than 100,000 customers and his success was acknowledged by Queen Victoria in 1887 with a knighthood. His Royal Welsh Warehouse Company produced its own mail order catalogues from 1890, after a printing press was installed in his Newtown premises. In the summer catalogues there are many items of leisure and sporting wear

available. As with many modern mail order catalogues, the emphasis was very much on women's clothing. The men's catalogue was not as large, but featured cloth samples, pants, vests, surplices, cassocks, collars, cuffs, shirts and cricket, tennis and boating outfits. There were also home furnishing and children's catalogues. Pryce-Jones was elected member of Parliament for the area in 1885. Mail order became a global phenomenon and a way of life, especially in the United States, providing a shopping lifeline for its sparsely populated rural communities. Pryce-Jones changed the nature of retailing across the world. Internet shopping has damaged catalogue shopping in the last decade or so, but the underlying principle of internet marketing is essentially the same.

THE FIRST MAIL ORDER COMPANY

MOST SOURCES relate that Aaron Montgomery Ward started the mail order industry in 1872, in Chicago with two employees and a catalogue of 163 products. However, by this time Pryce-Jones was known across the world and was also selling in the USA. Pryce-Jones was excellent at drumming up publicity for his rapidly growing mail order drapery business. His pamphlet for 1869 illustrates his company's awards for the best Welsh flannel at the Grand National Eisteddfod of Wales in 1865, 1866, 1868 and 1869, so customers could be assured that they were buying the best. By the 1860s his sales leaflets were offering general household goods and clothing, well before Montgomery Ward.

PASTEURIZATION

—— 1862 ——

LOUIS PASTEUR 1822–1895 AND CLAUDE BERNARD 1813–1878, FRANCE

Pasteur and Barnard showed in 1862 that the process of fermentation in wine could be halted by heating the drink for a few minutes. The wine was not boiled, but heated to about 135° F (57° C). The experiment was part of their research into preventing wine and beer from going sour. (The boiling temperature of red wine of 14.5 degrees proof is 190° F, 88° C). This process, called *pasteurization*, was enough to destroy microbes in milk, wine, beer, cheese, eggs and other foods. Pathogenic bacteria and viruses in

liquids can thus be eliminated by heating a liquid to a critical temperature for a specified amount of time. When a liquid is thus pasteurized, there are a still number of neutral or beneficial organisms remaining, as opposed to sterilization, which destroys all life forms. The components of milk make it an important part of our diet, but unfortunately they are also the same components that are ideal for disease-causing bacteria. Diseases that pasteurization can prevent include brucellosis, diphtheria, scarlet fever and Q-fever. The process kills the harmful bacteria, *E. coli* 0157, *Campylobacter, Salmonella*, *Listeria*, *Yersinia*, the TB bacillus and *Staphylococcus aureus* and other pathogens found in raw milk.

Pasteurization is typically associated with milk, and was first suggested by Franz Ritter von Soxhlet in 1886. It is the main reason for milk's extended shelf life. Currently milk is held at 145° F (63° C) for 30 minutes, or is subjected to 15 seconds of 162° F (72° C) heat, and then rapidly cooled in both cases. Whereas sterilization is designed to kill all micro-organisms in food, pasteurization aims for a reduction in the numbers of viable pathogens so that they are unlikely to cause disease. Commercial-scale sterilization of food is not common, as it adversely affects the taste and quality of the product. *High Temperature Short Time* (HTST) pasteurized milk has a refrigerated shelf life of two to three weeks, whereas *Ultra Pasteurized* (UHT) milk can last two to three months. UHT (ultra-high-temperature) milk or cream needs to be heated much more, between 280° to 302° F (138° to 150° C) for at least two seconds. It can then be stored without refrigeration for months at room temperature, packed in sterile, sealed containers, but once opened, the milk goes 'off' in the same amount of time as normal HTST milk. Unfortunately, pasteurization destroys some possibly beneficial enzymes and microbes. Milk pasteurization has been subject to increasing scrutiny recently, owing to the discovery of pathogens that are both widespread and heat resistant that are able to survive pasteurization in significant numbers. Perhaps we should look elsewhere for a more reliably healthy drink; as Pasteur himself wrote in *Études sur le Vin* (1866), '*Wine is the most healthful and most hygienic of beverages*.'

OPTICAL SPECTRA OF A NEBULA AND ORIGIN OF MATTER

—— 1864 ——

WILLIAM HUGGINS 1824–1910, ENGLAND

By discovering the gaseous nature of nebulae, Huggins proved Herschel's assertion that stars and planets could be formed from gas. Early users of the telescope had noted the existence of small, fairly luminous patches of light which they called *nebulae* (Latin for clouds). With larger and larger telescope apertures, more nebulae were resolved so that it was understood that each was a cluster of stars. The astronomer William Herschel (1738–1822) believed that all the nebulae in the universe were ultimately resolvable, if sufficient telescopic power was used. Herschel formulated the theory that they consisted of '*…primeval cosmic matter out of which future worlds were to be fashioned*'. He also believed that we might see in them some of the stages through which the stars and planets pass in their development from the luminous cloud. This was all that was known about nebulae when William Huggins began observing the night sky. He sold his family drapery business in London and became an 'amateur' astrophysicist in 1854. Like Faraday, Darwin and Rayleigh, Huggins worked '*for no other motive than intense love for research, undeterred by obstacles or by dearth of instrumental means*'. In 1856 he acquired his first telescope, of 5 inches (12.7 cm) aperture. Two years later he bought an 8-inch (20.3-cm) refractor, and with it made his visual observations of stellar and nebular spectra. In 1870 he mounted an 18-inch (45.7-cm) mirror on the London hilltop where he lived, and worked to the day of his death with no further increase in aperture. He was aware of every advance and of the development of great refractors, but did not have the means to purchase

one. He was also dissatisfied with the routine character of ordinary astronomical work, and was seeking newer methods for attacking problems of the heavenly bodies, particularly nebulae.

SPONTANEOUS GENERATION

'*Spontaneous Generation*' was the principle proposed by Aristotle that life could arise from inanimate matter, not needing 'parents', e.g. the 'spontaneous' appearance of maggots upon rotting meat. In an 1859 experiment Pasteur had boiled meat broth in a flask which had a long, downward curved neck. The flask remained free of any '*growth*' for an extended period. When the flask was turned so that particles could fall down the air bends, the broth became quickly clouded. By this simple experiment, Pasteur had proved that life could not generate itself within controlled conditions, and his discovery finally destroyed the age-old concept of spontaneous generation.

To early observers with lowresolution telescopes, the nebula named M27, and other subsequently discovered planetary nebulae, somewhat resembled the giant planets like Uranus, and Herschel, the discoverer of that planet, had coined the term *planetary nebula* for them. Huggins began to study the optical spectra of astronomical objects, using a prism to disperse their light. He was the first person to use spectroscopy to determine their compositions in 1861. Most early spectroscopy concerned the Sun, whose spectrum displayed numerous dark lines, the significance of which was not known. The spectra of stars were so faint, that little more could be done than group them into various types, in the hope (eventually fulfilled) that each type would correspond to a particular type of star, or a particular phase in an evolutionary cycle of star development. Huggins, however, determined to perfect his instruments to the point of permitting some genuine analysis of stellar spectra. By 1863 he had succeeded to the extent of being able to name some of the chemical constituents of several stars on the basis of numerous stellar emission lines. His findings on nebulae were spectacular. In 1864 Huggins discovered a bright nebula in the constellation *Draco* whose spectrum clearly indicated that it was a mass of glowing gas.

Huggins found evidence that both planetary and irregular nebulae consist of luminous gas, a conclusion supporting the nebular hypothesis of the origin of stars and planets, by condensation from glowing masses of fluid material. In 1866 he made the first spectroscopic examination of a temporary star (*Nova Coronae*), and found it to be enveloped in blazing hydrogen. In 1868 he proved incandescent carbon vapours to be the main source of cometary light. Huggins's work led to the discovery of helium, through analysis of the Sun's spectrum in 1868. Apart from hydrogen, helium is the most abundant chemical element in the universe, yet it was only discovered on the Earth in 1895. Huggins was the first to determine that the Sun and stars are composed mostly of the element hydrogen. By 1868 Huggins had established the truly revolutionary character of spectroscopy beyond all doubt. Celestial movements were what astronomers understood, and Huggins demonstrated movements of a kind unobtainable in any other way. By drawing an analogy with the shift of pitch that accompanies a moving source of sound waves (the Doppler Effect), he inferred, by measuring a shift in its spectral lines, that the bright star *Sirius* was moving away from the sun at a rate of 29 miles (47 km) per second.

THE PILLARS OF CREATION

NEBULAE OFTEN form star-forming regions, such as in the *Eagle Nebula*. This nebula is depicted in one of NASA's most famous images, the *Pillars of Creation*. In these regions the formations of gas, dust, and other materials

clump together to form larger masses, which attract further matter, and eventually will become massive enough to form stars. The remaining materials are then believed to form planets and the other objects which make up planetary systems.

Huggins’ wife Margaret Lindsay Murray Huggins (1848–1915) was a self-taught astronomer, who did extensive work in spectroscopy and photography. She extensively studied the *Orion Nebula*, one of the brightest nebulae. She and her husband were the first people to realize that some nebulae, like the Orion Nebula, consisted of amorphous gases and were not a cluster of stars, like the *Andromeda Galaxy*. When he published his report in 1886, Huggins had examined the spectra of more than 60 nebulae and clusters. Of these about one-third belonged to the class of gaseous bodies. The existence of the gaseous nebulae gave evidence in support of the primordial gas in the theories of Herschel and Laplace. Huggins also demonstrated the absence of any atmosphere on the Moon by the lack of any refraction of starlight.

The real triumphs of photographic astronomy began in 1875 with Huggins’s adoption and adaptation of the gelatine dry plate, instead of the wet collodion process. This enabled the observer to make exposures of any desired length, and, through the cumulative action of light on extremely sensitive surfaces, to obtain permanent accurate pictures of celestial objects so faint as to be completely invisible to the eye even when aided by the most powerful telescopes. In the last quarter of the 19th century spectroscopy and photography together worked a revolution in observational astronomy, and in both branches Huggins acted as pioneer.

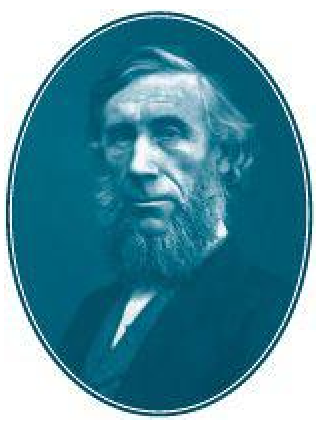
GREENHOUSE EFFECT

—— 1865 ——

JOHN TYNDALL 1820–1893, IRELAND AND ENGLAND

Tyndall made many contributions to science, the most important being the proof that certain gases affect the Earth’s climate more than others. The term *greenhouse effect* originated in 1827 with work carried out by the French mathematician and scientist, Jean Baptiste Fourier (1768–1830). He observed in *Theorie Analytique de la Chaleur* that certain gases trapped

heat in the atmosphere and coined the phrase due to its similarity to the gardening phenomenon. Fourier said that the atmosphere was like the glass in a greenhouse. It let the Sun's rays in and therefore the warmth, but it also provided a barrier which prevented the accumulated heat from escaping again. Beginning his career as a railway engineer, John Tyndall was in turn a draftsman, surveyor, physics professor, mathematician, geologist, atmospheric scientist, public lecturer and mountaineer. From 1853 for 34 years he was Michael Faraday's successor as professor of physics at the Royal Institution. In 1859, after contributing to the field of diamagnetism, Tyndall began studying the radiating properties of various gases. He constructed the first ratio spectrophotometer, which he used to measure the absorptive powers of gases such as water vapour, carbonic acid (now called carbon dioxide), ozone and hydrocarbons. Among his most important discoveries were the vast differences in the abilities of '*perfectly colourless and invisible gases and vapours*' to absorb and transmit radiant heat. He noted that oxygen, nitrogen and hydrogen are almost transparent to radiant heat while other gases are quite opaque. Tyndall's experiments showed that molecules of water vapour, carbon dioxide and ozone are the best absorbers of heat radiation, and that even in small quantities, these gases absorb much more strongly than the atmosphere itself.



He was the first to correctly measure the relative infrared absorptive powers of the gases nitrogen, oxygen, water vapour, carbon dioxide, ozone, methane, etc. Tyndall then concluded that among the constituents of the atmosphere, water vapour is the strongest absorber of radiant heat (now called infrared radiation) and is therefore the most important gas controlling Earth's surface temperature. He asserted that without water vapour the

Earth’s surface would be ‘*held fast in the iron grip of frost*’. He later speculated on how fluctuations in water vapour and carbon dioxide could be related to climate change. Others had speculated about the greenhouse effect, but Tyndall was the first to prove it. He stated: ‘*The waves of heat speed from our earth through our atmosphere towards space. These waves dash in their passage against the atoms of oxygen and nitrogen, and against molecules of aqueous vapour. Thinly scattered as these latter are, we might naturally think of them meanly as barriers to the waves of heat.*’ In the 1860s Tyndall began to suggest that slight changes in the atmospheric composition could bring about climatic variations.

THE IMPORTANCE OF WATER VAPOUR

TYNDALL IDENTIFIED that there was evidence of a greenhouse effect, whether natural or man-made (anthropogenic). Regarding water vapour he wrote that: ‘…*this aqueous vapour is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air that overspreads this country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost … its presence would check the earth’s loss; its absence without sensibly altering the transparency of the air, would open wide a door for the escape of the earth’s heat into infinitude.*’

Tyndall related his radiation studies to minimum night-time temperatures and the formation of dew, correctly noting that dew and frost are caused by a loss of heat, through radiating processes. He even correctly considered London as a *heat island*, meaning he thought that the city was warmer than its surrounding areas. Among his other research areas, he perfected a bacteria-free box, helping prove Pasteur’s germ theories. He knew that all bacteria are killed by boiling but discovered that they have a spore form that can survive boiling. Tyndall found a way to eradicate the spores that came to be known as *Tyndallization*. Professor Tyndall visited the Alps in 1849, and began to go there yearly to research glacier formation. He was one of the first men to ascend the Matterhorn and the first to climb the Weisshorn.

In 1856 he made an expedition to Switzerland with T.H. Huxley, which resulted in a joint treatise *On the Structure and Motion of Glaciers*. His other publications include *The Glaciers of the Alps* (1860), *Mountaineering* (1861), *Heat as a Mode of Motion* (1863), *On Radiation* (1865), *On Sound* (1867), *On Light* 1870 and *The Forms of Water in Clouds and Rivers, Ice and Glaciers* (1872). His works attracted the attention of the whole scientific world, and stimulated new fields of research.

BLUE SKIES

TYNDALL WAS the first man to discover why the sky is blue, because large molecules in the atmosphere scatter blue light from the Sun's rays more strongly than other colours. He also explained that when the Sun is close to the horizon, light has to travel further through the atmosphere to the observer, so blue and other light is more scattered, leaving red light, which is why we have the *Tyndall Effect* at dusk and dawn.

KINETIC THEORY OF GASES

—— 1866 ——

JAMES CLERK MAXWELL 1831–1879, SCOTLAND

The founder of modern physics, Maxwell laid the foundation for fields such as special relativity and quantum mechanics. A mathematician, Maxwell is regarded with Einstein and Newton as one of the leading three physicists of all time, carrying out revolutionary work in electromagnetism and the kinetic theory of gases. The three-colour method, which is the foundation of virtually all practical colour processes whether chemical or electronic, was first suggested in an 1855 paper on colour vision by Maxwell. The world's first colour photograph was made according to Maxwell's instructions. A set of three monochrome 'colour separations' was taken by Thomas Sutton in 1861 to illustrate a lecture on colour by Maxwell, and shown in colour by the triple projection method. By the trichromatic process, using red, green and blue filters, he reproduced a Scottish tartan ribbon. The process was the forerunner of today's modern colour photography

His first major contribution to science was a study of the planet Saturn's rings. He showed that stability could be achieved only if the rings consisted of numerous small solid particles, an explanation only recently proved by a space probe. Maxwell then considered molecules of gases in rapid motion. By treating them statistically he was able to formulate in 1866, independently of Ludwig Boltzmann, the *Maxwell-Boltzmann kinetic theory of gases*. This demonstrated that temperatures and heat involved only molecular movement. This meant a change from a concept of certainty (with heat viewed as flowing from hot to cold) to one of statistics (where molecules at high temperature have only a high probability of moving towards those at low temperature.) Maxwell made fundamental contributions to the development of thermodynamics, and his theory provided the new subject of statistical physics, linking thermodynamics and mechanics. It is still widely used as a model for rarefied gases and plasmas.

GENETICS

—— 1866 ——

GREGOR JOHANN MENDEL 1822–1884, MORAVIA, HOLY ROMAN EMPIRE

Mendel was an Augustinian friar and biologist, who became the first person to trace the characteristics of successive generations of a living thing, and his pioneering work gives us *Mendel's Laws of Inheritance*. He lived at the Augustinian monastery of St Thomas at Brno, Moravia, which is now in the Czech Republic. On one of his walks around the monastery,

he found an atypical variety of an ornamental plant. He took it and planted it next to the typical variety. He grew their progeny side by side to see if there would be any approximation of the traits passed on to the next generation. His experiment was designed to support or to illustrate Lamarck's views concerning the influence of environment upon plants. He found that the next generation of the plants retained the essential traits of the parents, and therefore were not influenced by the environment. Mandel's simple test gave him the idea of heredity. He saw that the traits were inherited in certain numerical ratios, so he conceptualized *dominance* and *segregation* of genes. Mendel set out to test his ideas upon peas, which he grew in the monastery garden. Between 1856 and 1863 Mendel cultivated and tested around 28,000 pea plants, analyzing seven pairs of seeds for comparisons of such characteristics as the shape of seeds, their colour, and whether they were tall-stemmed or short-stemmed plants.

He methodically self-pollinated and wrapped each individual plant to prevent accidental pollination by insects. Mendel collected the seeds produced by the plants and studied the offspring of these seeds, observing that some plants bred true and others did not. Mendel discovered that by crossing tall and short parent plants, he achieved hybrid offspring which resembled the tall parent, rather than being a medium-height blend. He then conceived the concept of *heredity units*, which we now call *genes*, often expressed as *dominant* or *recessive* characteristics. Mendel then worked out the pattern of inheritance of various traits, and his generalizations became known as the basic *laws of heredity*. Hereditary factors do not combine, but are passed on intact. Each member of the parental generation transmits only half of its hereditary factors to each offspring (with certain factors *dominant* over others). Different offspring of the same parents receive different sets of hereditary factors. *Dominance* was the term used for a trait that turns up in an offspring. *Recessiveness* was the term for a trait which was masked by a dominant gene.

THE DIFFICULTIES OF EXPERIMENTS

‘*THAT NO generally applicable law of the formulation and development of hybrids has yet been successfully formulated can hardly astonish anyone who is acquainted with the extent of the task and who can appreciate the difficulties with which experiments of this kind have to contend.*’ Johann Gregor Mendel, *Experiments on Plant Hybrids*, 1865

Mendel published his work on heredity in a short monograph in 1866, *Experiments with Plant Hybrids*, in the *Journal of the Brno Natural History Society*. The complex and detailed work was not understood even by influential people in his field, and the journal was little known, so its findings were not widely disseminated. Mendel made an attempt to contact important scientists abroad, sending them reprints of his work, but in general they ignored an unknown author writing in an obscure journal. Two years after the publication of his paper, Mendel was elected abbot of the monastery and he devoted himself to his duties until his death 16 years later. The great Czech composer Leoš Janáček played the organ at Mendel’s funeral, but the new abbot of the monastery burned all Mendel’s research papers. Not until 1900, 34 years after its publication, was his work

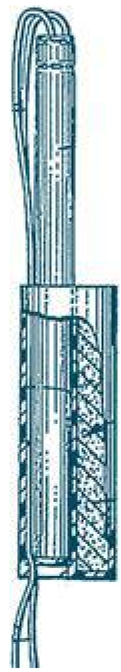
recognized by three independent investigators, including the Dutch botanist Hugo De Vries. However, not for another quarter of a century was the real significance of his work appreciated, particularly in relation to evolutionary theory. Scientists demonstrated that the theory of evolution could be described in terms of the change in gene frequency of Mendelian pairs of characteristics in a population, over successive generations. Mendel's work on heredity became the basis of the modern theory of genetics.

DYNAMITE AND GELIGNITE

—— 1867 *and* 1875 ——

ALFRED BERNHARD NOBEL 1833–1896, SWEDEN

In 1842 Nobel's family moved from Sweden to Russia, where his father Immanuel had opened an engineering firm providing military equipment for the tsar. In 1850 Nobel's father sent Alfred abroad to study chemical engineering in Europe and the USA, but he returned to Sweden in 1863 with his father after the family firm went bankrupt. Alfred Nobel's brother Emil was killed in a nitroglycerine explosion in 1864. Alfred Nobel now devoted himself to the study of explosives, becoming particularly interested in the safer manufacture and use of nitroglycerine, a highly unstable explosive. Nobel thus incorporated nitroglycerine into silica, an inert substance, which made it safer and easier to handle. He patented his invention in 1867 under the name of '*dynamite*', and it was soon used in cutting canals, blasting tunnels and building railways and roads across the world. Dynamite is a high explosive, which detonates with 60 per cent more energy density than TNT. It quickly gained global popularity as it was far safer than gunpowder or nitroglycerine. Dynamite is usually sold in the form of an 8-inch (20-cm) long stick, weighing about half a pound (225 g), and should be used within a year of manufacture. Nobel, perhaps misguidedly, considered that his work was a way of promoting peace, not war. He wrote, '*My dynamite will sooner lead to peace than a thousand world conventions. As soon as men will find that in one instant, whole armies can be utterly destroyed, they surely will abide by golden peace.*'



Still deeply shocked by his brother’s early death, Nobel knew that even dynamite in certain conditions became unstable, and he worked on producing ever safer explosives. By 1875 Nobel had developed *gelignite* (blasting gelatine), also known as *jelly*, from collodion-cotton (a type of gun-cotton, or nitrocellulose). It was dissolved in nitroglycerine or nitroglycol, and mixed with wood pulp and saltpetre. Unlike dynamite, gelignite does not suffer from *sweating*, the leakage of nitroglycerine from the solid matrix containing it. Gelignite can be easily moulded and is safe to handle, as it cannot explode without a detonator. Because of its universal civilian use in quarries and mining, it has often been stolen and used by revolutionaries and criminals. In the 1870s and 1880s Nobel built up a network of 90 factories across Europe to manufacture his explosives. In 1894, he bought an ironworks at Bofors in Sweden that later became the Bofors arms factory. Nobel continued to work in his laboratory, inventing a number of synthetic materials, and by the time of his death he had registered 355 patents.

NOBEL’S PREMATURE OBITUARY

NOBELS’ ‘safer’ explosives revolutionized mining and civil engineering, saving many thousands of lives. However, the death of his brother Ludvig in 1888 caused several newspapers mistakenly to publish obituaries of

Alfred Nobel. A French obituary of 12 April stated '*Le marchand de la mort est mort*' ('The merchant of death is dead') because of the uses of explosives in warfare. Another stated that Nobel '*became rich by finding ways to kill more people faster than ever before*'. Horrified by what the world thought of him, upon his death eight years later Nobel left instructions that most of his massive fortune should be used to endow annual Nobel Prizes.

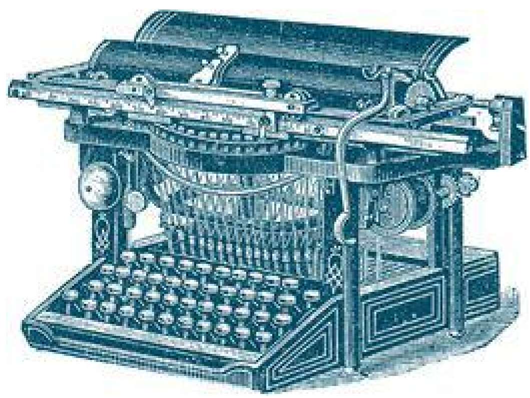
TYPEWRITER

—– 1868 —–
(*production* 1873, *patented* 1874)
CHRISTOPHER LATHAM SHOLES 1819–1890, UNITED STATES

For a century, mechanical and then electric typewriters were essential for business, and the 'QWERTY' keyboard layout is still used on modern computers. Christopher Sholes was an American mechanical engineer, who invented the first practical modern typewriter in 1868, with the financial and technical support of his business partners Samuel Soule and Carlos Glidden. Five years, dozens of experiments, and two patents later, Sholes and his associates produced an improved model similar to today's typewriters. The name QWERTY for our typewriter keyboard comes from the first six letters in the top alphabet row (the one below the numbers). People have accused Sholes of deliberately arranging his keyboard to slow down fast typists, who would otherwise jam up his sluggish machine. However, his motives were different.

In 1868 the keys were arranged alphabetically in two rows. The crude machine-shop tools available could not produce a precision instrument, so the first typewriter often jammed when someone tried to type quickly with it. Sholes solved the problem by rearranging the letters. His initial typewriter had its letters on the end of rods called 'typebars', which hung in a circle. The roller which held the paper sat over this circle, and when a key was pressed, a typebar would swing up to hit the paper from underneath. If two typebars were near each other in the circle, they would tend to clash into each other when typed in succession. Sholes therefore decided to take the most common letter pairs such as TH and ES and make sure their typebars hung at safe distances from each other. He did this using a study of

letter-pair frequency prepared by the educator Amos Densmore, brother of James Densmore. James Densmore bought the patent off Sholes for $12,000. Thus the typebars were hung in a nonalphabetical and ergonomic sequence. The layout of the QWERTY keyboard itself was determined by the existing mechanical linkages of the typebars inside the machine to the keys on the outside. Sholes's solution did not eliminate the problem of clashing typebars completely, but it was greatly reduced. His new keyboard arrangement was considered important enough to be included on Sholes's patent granted in 1878, some years after the machine went into production. QWERTY's effect, by reducing those clashes, was to speed up typing.



Having bought the patent, James Densmore went to Remington, the sewing-machine manufacturer, to have the machines mass-produced. In 1873, the first *Sholes and Glidden Patent TypeWriter* appeared on the market. A foot treadle was provided for the carriage return. This was probably because William Jenne, the Remington engineer who set up the typewriter factory, had been transferred from Remington's sewing machine division. It was not a great success (fewer than 5000 were sold), but it founded a worldwide industry, and it brought mechanization to dreary, time-consuming office work. Sales of the typewriter did not take off until after Remington's second model was introduced in 1878, offering the only major modification to the keyboard as we know it today. The 1873 machines typed only capital letters. However, the new *Remington No. 2* offered both upper and lower case by adding the familiar *shift key*. It is called a shift because it actually caused the carriage to shift in position, for printing either of two letters on each typebar. Modern electronic machines no longer shift mechanically when the shift key is pressed, but the name remains the same. Other improvements made by Remington engineers gave the typewriter

machine its market appeal, and sales skyrocketed in the 1880s. Arduous handwriting tasks could be carried out in minutes on the machine, leaving time to enjoy the ‘*finer things in life*’. The first Remington advertisements declared: ‘*To save time is to lengthen life*.’

Because the typebars of the Remington typewriter struck upwards, the typist could not see characters (and mistakes) as they were being typed, until a carriage return caused the typing to scroll into view. The difficulty with any other arrangement was ensuring the typebars fell back down into place reliably when the key was released. This was eventually achieved, and so-called *visible typewriters* were introduced in 1895. These first machines were also heavily influenced by the workings and appearance of Remington’s sewing machines. The machine began appearing in homes and offices around the USA and Europe, and created a new source of employment, typing. During the 1880s many different types of typewriters were designed, but the one which developed the style we recognize today was the *Underwood No.1*. George K. Anderson of Memphis, Tennessee patented the typewriter ribbon in 1886.

THE FIRST TYPING AUTHOR

MARK TWAIN (Samuel Clemens 1835–1910) seems to have first used a Sholes and Glidden typewriter on 9 December 1874. Two letters of that day encapsulate his early feelings towards the machine. The first, to his brother Orion, contains praise for the invention: ‘*This is the first attempt I ever have made, and yet I perceive that I shall soon and easily acquire a fine facility in its use.*’ By the time he typed the second letter, to his friend the author and literary critic William Dean Howells, his enthusiasm was waning: ‘*Blame my cats but this thing requires genius in order to work it just right.*’ Twain enjoyed and made use of new inventions, and was the first author to submit a typewritten manuscript to his publisher. He wrote: ‘*In a previous chapter of this “Autobiography” I have claimed that I was the first person in the world that ever had a telephone in the house for practical purposes; I will now claim – until dispossess – that I was the first person in the world to apply the type-machine to literature. That book must have been “The Adventures of Tom Sawyer”. I wrote the first half of it in ’72, the rest of it in ’74. My machinist type-copied a book for me in ’74, so I concluded it was*

that one. That early machine was full of caprices, full of defects – devilish ones. It had as many immoralities as the machine of today has virtues.'

PERIODIC TABLE

—– 1869 —–

DIMITRI MENDELEEV 1834–1907, RUSSIA

The *periodic table* accurately predicts the abilities of various elements to combine into chemical compounds, and use of the periodic table is now ubiquitous in chemistry, providing a useful framework to classify, systematize and compare many of the many different forms of chemical behaviour. A professor at St Petersburg University, Mendeleev is best known for his work in arranging the 63 known elements into his *periodic table* based upon atomic mass, which he published in *Principles of Chemistry* in 1869. His first periodic table was compiled on the basis of arranging the elements in ascending order of atomic weight, and grouping them by similarity of properties. His organization surpassed previous attempts at classification of elements. Mendeleev predicted the existence and properties of new elements and pointed out accepted atomic weights that were in error. He provided for variance from strict atomic weight order, left space for new elements, and predicted three yet-to-be-discovered elements including eka-silicon and ekaboron. His table did not include any of the *noble gases* as they had not yet been discovered. These are chemical elements with very similar properties under standard conditions, being colourless, odourless and monatomic, with very low chemical reactivity. The six noble gases which occur naturally are helium, neon, argon, krypton, xenon and radon.

The original table has been modified and corrected several times, notably by Henry Moseley (see box below), but Mendeleev had accommodated the discovery of isotopes, rare gases, etc. Possibly the greatest strength of Mendeleev's table is that his original version accurately predicted of the properties of unknown elements expected to fill gaps in his arrangement. For example, *eka-aluminium*, expected to have properties intermediate between aluminium (element number 13) and indium (49), was discovered with those properties in 1875 and named gallium (31). No gaps remain in the current 118-element periodic table. All of the elements from hydrogen

to plutonium, except technetium, promethium and neptunium, exist in the Earth in macroscopic or recurrently produced trace quantities. The three exceptions do exist naturally, but only in trace amounts, and as the result of rare nuclear processes from decay of heavy elements. Every element through to copernicium, element 112, has been isolated, characterized and named, and elements 113 to 118 have been synthesized in laboratories around the world. Research into producing additional synthetic elements beyond atomic number 118 is being pursued. The table has found many applications not only in physics and chemistry, but also in such diverse fields as agriculture, medicine, nutrition, environmental health, engineering, geology, biology, materials science and astronomy.

WHO WAS MOSELEY?

THE BRITISH chemist Henry Moseley (1887–1915) studied under Rutherford. Moseley brilliantly developed the application of X-ray spectra to study atomic structure, and his discoveries resulted in a more accurate positioning of elements in the periodic table, by closer determination of atomic numbers. Tragically for the development of science, Moseley was killed aged 28 in action at Gallipoli in 1915. In 1913 Moseley had published the results of his measurements of the wavelengths of the X-ray spectral lines of a number of elements, which showed that the ordering of the wavelengths of the X-ray emissions of the elements coincided with the

ordering of the elements by atomic number. With the discovery of isotopes of the elements, it became apparent that *atomic weight* was not the significant player in the *periodic law* as Mendeleev, Meyers and others had proposed. Rather, the properties of the elements varied periodically with *atomic number*. When atoms were arranged according to increasing atomic number, the few problems with Mendeleev's periodic table had disappeared. Because of Moseley's work, the modern periodic table is based on the atomic numbers of the elements.

ORGANIZATION OF THE TABLE

IT IS A tabular display of the 118 known chemical elements, organized by selected properties of their atomic structures. Elements are presented by increasing atomic numbers, beginning with hydrogen at 1, signifying the number of protons in an atom's nucleus. The 118th element is ununoctium, the only synthetic member of group 18. While rectangular in general outline, gaps are included in the horizontal rows (known as *periods*) thus keeping elements with similar properties together in vertical columns (known as *groups*), e.g. noble gases, alkali metals, alkali earths and halogens. Elements in groups have some similar properties to each other. The periodic table is a masterpiece of organized chemical information. The evolution of chemistry's periodic table into the current form is an astonishing achievement with major contributions being recorded over the years from many eminent scientists.

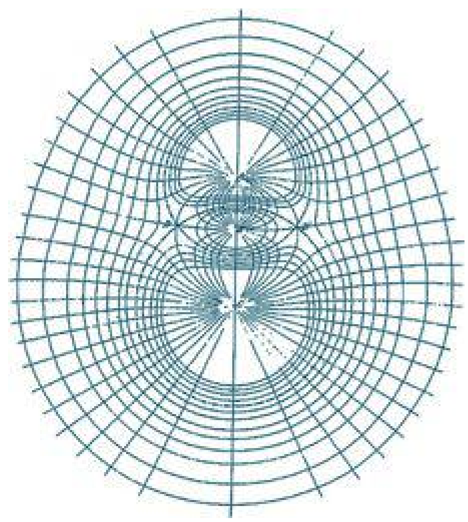
ELECTROMAGNETIC FIELD THEORY

—— 1873 ——

JAMES CLERK MAXWELL 1831–1879, SCOTLAND

Between 1864 and 1873, Maxwell demonstrated that a few relatively simple mathematical equations could express the behaviour of electric and magnetic fields, and their interrelated nature. He explained that an oscillating electric charge produces an electromagnetic field. His four partial differential equations first appeared in fully developed form in *Electricity and Magnetism* (1873). Since known as *Maxwell's equations*,

they are one of the great achievements of 19th-century physics. Before Maxwell there was no concept of a comprehensive theory of electricity and magnetism. Maxwell pointed the way to the existence of the spectrum of electromagnetic radiation. He defined fields as a tension in the medium, and stated a new concept, that energies resides in fields as well as bodies. This pointed the way to the application of electromagnetic radiation for such present-day uses as radio, television, radar, infra-red telescopes, microwaves and thermal imaging. Calculating the speed of electromagnetic waves, Maxwell postulated that light is a form of electromagnetic radiation exerting pressure and carrying momentum. Maxwell demonstrated that electric and magnetic fields travel through space in the form of waves, at the constant speed of light. This provided the basis for Einstein's work on relativity from which the relationship between energy, mass and velocity, contributed to the theory underlying the development of atomic energy.



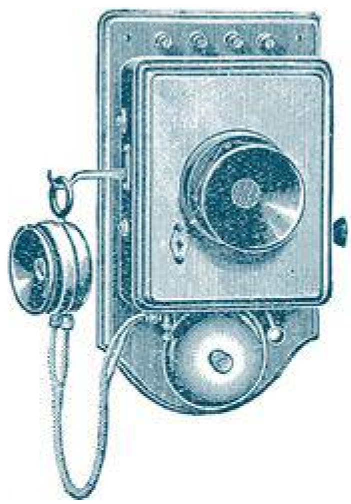
TELEPHONE

—— 1876 ——

ALEXANDER GRAHAM BELL 1847–1922, SCOTLAND AND CANADA

Telephones are designed around four basic elements: a microphone to speak into, an earphone to reproduce the voice of the other person, a ringer which makes a sound to alert the owner when a call is coming in, and a dial (later a keypad) to enter the number of the telephone being called. Until the 1950s a caller had to dial a switchboard operator who would '*put you*

through' to the number you required. Landline telephones are connected by a pair of wires to the telephone network, while a mobile phone or cell phone is portable and communicates with the telephone network by radio. The microphone converts the sound waves from your voice into electric signals to send to the other phone, where they are converted back into sound waves by the earphone. Communications now pass through a global network of telephone lines, cellular networks, undersea telephone cables, fibre-optic cables and communications satellites. These are connected by switching centres, enabling any telephone to communicate with any other. The telephone voice communication system has been adapted for data communication such as telex, facsimile (fax) and dial-up internet. Today there are 1.3 billion phone lines in use around the world.



Credit for the invention of the *electric telephone* is disputed, as it is for radio, television, the light bulb, computer, etc. Several inventors pioneered experimental work on voice transmission over a wire, improving upon each other's ideas. In 1844 Innocenzo Manzetti first proposed the concept of a *speaking telegraph*, and in 1854 Charles Bourseul published *Transmission électrique de la parole* ('Electric transmission of speech'). In 1861, Johann Reis in Frankfurt managed to transmit continuous musical sound, but indistinct speech. (In 1875, Edison received a translation of the description of this experiment, so his scientists copied and improved the Reis telephone.) In 1871 Antonio Meucci filed a patent caveat for a *Sound Telegraph* for the communication of voice between two people by wire, but after renewing it twice, he allowed it to lapse in 1874. David Hughes had

made innovations necessary for telephony, the most important being the carbon microphone of 1877. However, Bell was the first to be awarded a US patent for the electric telephone, from which all other patents for electric telephone devices and features developed.

THE SPEED OF ADOPTION OF THE TELEPHONE

ONLY 14 years after its invention, Mark Twain wrote the following wry observation in his Christmas greeting card of 1890: '*It is my heart-warmed and world-embracing Christmas hope and aspiration that all of us, the high, the low, the rich, the poor, the admired, the despised, the loved, the hated, the civilized, the savage (every man and brother of us all throughout the whole earth), may eventually be gathered together in a heaven of everlasting rest and peace and bliss, except the inventor of the telephone.*'

THE FIRST TELEPHONE CONVERSATION

'*I THEN shouted into M* [the mouthpiece] *the following sentence: "Mr. Watson – Come here – I want to see you." To my delight he came and declared that he had heard and understood what I said. I asked him to repeat the words. He answered "You said – Mr. Watson – Come here – I want to see you." We then changed places and I listened at S* [the reed receiver] *while Mr. Watson read a few passages from a book into the mouth piece M. It was certainly the case that articulate sounds proceeded from S. The effect was loud but indistinct and muffled. If I had read beforehand the passage given by Mr. Watson I should have recognized every word. As it was I could not make out the sense – but an occasional word here and there was quite distinct. I made out "to" and "out" and "further"; and finally the sentence "Mr. Bell do you understand what I say? Do – you – un – der – stand – what – I – say" came quite clearly and intelligibly. No sound was audible when the armature S was removed.*' Alexander Graham Bell, *Notebook, Experiments made by A. Graham Bell*, recording the entry for 10 March 1876.

Elisha Gray, an American electrical engineer, and Bell competed to make the first working telephone in the 1870s, Bell winning in a photo-finish. In a letter of 1 July 1875, Bell wrote: '*Grand telegraphic discovery today …*

Transmitted vocal sounds for the first time … With some further modification I hope we may be enabled to distinguish … the "timbre" of the sound. Should this be so, conversation viva voce by telegraph will be a fait accompli.' In April 1875 Bell's US patent for using multiple vibrating steel reeds in make-break circuits was granted, titled '*Transmitters and Receivers for Electric Telegraphs*'. In March 1876, his US patent '*Improvements in Telegraphy*' was granted, covering '*the method of, and apparatus for, transmitting vocal or other sounds telegraphically … by causing electrical undulations, similar in form to the vibrations of the air accompanying the said vocal or other sound.*' In the same month, the first successful telephone transmission of clear speech using a liquid transmitter was made when Bell spoke into his device, '*Mr. Watson – Come here – I want to see you*'. His assistant Watson heard each word distinctly. In January 1877 Bell was granted a US patent for an electromagnetic telephone using permanent magnets, iron diaphragms and a call bell. In April 1877 Edison filed for a patent on a carbon (graphite) transmitter, which was not granted for 15 years because of litigation. Tivadar Puskás (1844–1893), a Hungarian engineer, invented the telephone switchboard in 1877, which allowed for the formation of telephone exchanges, and eventually networks. Puskás had been working on a telegraph exchange when he heard of the telephone, and he contacted Edison with the idea of a telephone exchange. Working for Edison in Europe, Puskás set up the first telephone exchange in Paris in 1879.

MODERN STEEL INDUSTRY, CARNEGIE PROCESS

—— 1877 ——

SIDNEY GILCHRIST THOMAS 1850–1885 AND PERCY GILCHRIST 1851–1935, WALES

The 1856 '*basic Bessemer process*' of steel production was invented by a Welshman, George Parry, a chemist at the Ebbw Vale ironworks. It was sold to Henry Bessemer for the enormous sum of £30,000 (worth £20 million today using the average earnings index.) Parry got £10,000 and the owners of the ironworks received £20,000. Parry had used pig iron from Blaenafon, which was phosphorous-free, which had massive implications. Henry Bessemer was trying to design guns, and he needed to know how to

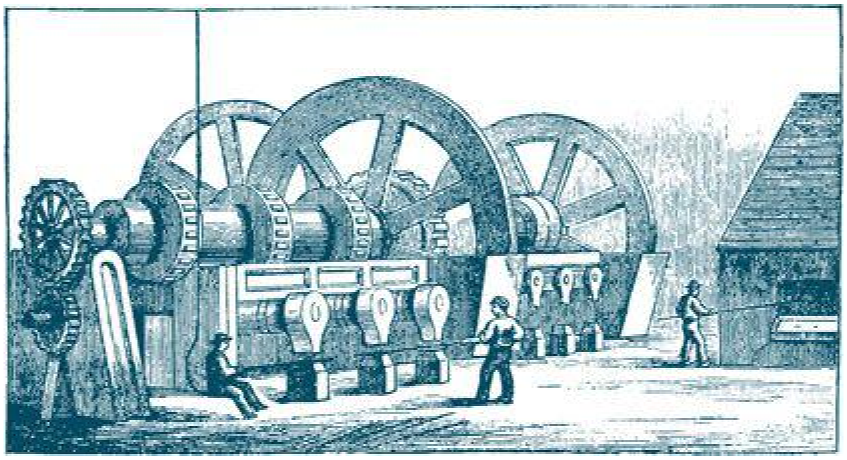
manufacture better quality iron in greater quantities. His ‘Bessemer process’ involves a converter where air is blown through molten cast iron to make bulk steel. The violent reaction removed carbon from the iron, making mild steel instead of wrought iron. The process could not be used for iron ores that included phosphorous, however, so non-phosphoric ores had to be imported from Sweden or Spain for the process. Phosphorous made steel very brittle, and was present in over 90 per cent of European iron ores, and around 98 per cent of American ore, making Parry’s Bessemer process non-economic.

THE THOMAS PROCESS AND THE FIRST WORLD WAR

GERMANY WAS not a serious rival to Britain in steel production until the ‘*minette*’, the phosphoric ores of Lorraine, were made available for industrial use by virtue of the Gilchrist-Thomas process. British historian R.C.K. Ensor observed that ‘*the discovery created a gigantic German steel industry which would not have been possible without it; and this, which by 1895 had a larger output than the British, played a very important part in predisposing Germany to aggressive war and enabling her after 1914 to sustain and prolong it.*’

From 1870, Sidney Gilchrist Thomas had been engaged in experimentation to solve the problem of de-phosphorizing pig iron. In the other main process used in steel making, the Siemens-Martin process, the problem of brittle steel also occurred, and steel foundries across the world were employing the greatest scientists of the age to try to solve the problem. Towards the end of 1875 Sidney Gilchrist Thomas discovered a provisional solution, and passed his findings to his cousin, the industrial chemist Percy Gilchrist, then working at a large iron-works in Blaenafon. Both men carried out more experiments. In 1877 the cousins found out how to remove the phosphorous. Regrettably Sidney Gilchrist Thomas died just seven years later, probably as a result of his continuous experiments while wearing little protection, at the age of thirty-five. In 1878 he sensationally announced his invention to the Iron and Steel Institute of Great Britain, and took out his first patent. On 4 April 1879 the experiments carried out by Sidney in his home laboratory, and at Blaenafon by Percy, were confirmed in a demonstration in Middlesborough with a 33,000-lb (15,000-kg)

converter. Steel producers from all over the world rushed to London to buy the *exploiting licence* of the new patent. Just one example was the Luxembourg-German producer Metz & Cie, which obtained its licence just 16 days after the successful trial, and immediately built a new steelworks to take advantage of the process.



The basis of Thomas's invention was the replacement of the acidic fireclay refractory lining in the Bessemer converter. Instead he used a basic lining of calcined dolomite. The addition of limestone then allowed the formation of a basic slag which absorbed the phosphorous as it was oxidized from the molten metal. Bessemer 'converters' were adopted across Europe, and the process was also used by the openhearth steelmakers. This was the 'basic process' used across the world until the introduction of the *Basic Oxygen process*, which also relies upon Thomas's invention. Steel production worldwide soared, which led to a great increase in the amount of slag remaining in converters. Because Thomas's process was known as 'basic', as he had added a chemically basic lining to the converter, it was called *basic slag*. Thomas experimented on it, and discovered that it made an excellent soil fertilizer. This phosphate-rich fertilizer is called *Thomasmehl* ('flour of Thomas') in German. An obelisk in Blaenafon commemorates the cousins for the '*invention (which) pioneered the basic Bessemer or Thomas process*'.

Andrew Carnegie (1835–1919) bought the rights to the 'Thomas process', and then made a fortune in the USA and elsewhere from what is known today as *the Carnegie process* (replicating George Parry's sale of his 'process' to Bessemer). Carnegie admitted that the *Carnegie process* was

not his, stating: ‘*These two men, Thomas and Gilchrist of Blaenavon, did more for Britain’s greatness than all the kings and queens put together. Moses struck rock and brought forth water. They struck the useless phosphoric ore and transformed it into steel, a far greater miracle*’. Sidney Gilchrist Thomas’s invention allowed the manufacture of high-grade steel using ores with phosphorous content, opening up the vast reserves of phosphoric ores to steel production across the world. His discovery vastly accelerated industrial expansion in Europe and America. These refiners of the Bessemer process and inventors of the Carnegie process had changed the world. In 1890 Britain was the world’s greatest steel producer, but by 1902 this great invention had allowed Carnegie, and the manufacturer Krupp of Essen in Germany to propel the United States and Germany into the first two places in steel production.

OIL TANKER

—— 1878 ——

LUDVIG IMMANUEL NOBEL 1831–1888, SWEDEN AND RUSSIA

The elder brother of Alfred Nobel, Ludvig’s factory in St Petersburg made cast-iron gunshells and gun carriages. Ludvig sent his younger brother Robert to southern Russia to source wood for gun stocks for the tsar. Luckily, Robert found petroleum oil instead and the brothers set up an oil distillery in Baku, Azerbaijan. By 1879 Ludvig’s company Branoble controlled the massive Russian oilfields and he set up research laboratories to find new uses and develop new products from the substance. Nobel invented better oil pipelines and refineries, and designed a new ship to transport oil. Pennsylvania oil was at this time transported by ship in heavy wooden barrels, each holding only 40 US gallons (150 lit). The barrels tended to leak, and were generally used only once. Hence they were very expensive, accounting for half the cost of petroleum production. An oil-tank steamer had been built in Britain for Belgian owners in 1874, but the USA and other authorities would not allow it near port, fearing fire and spillage problems. Nobel realized that he not only needed to keep the cargo and fumes well away from the engine room to avoid fires, but also to allow the oil to expand and contract when the temperature changed, and to properly ventilate the dangerous cargo. His *Zoroaster* was the world’s first successful

oil tanker, soon being widely copied, as Nobel refused to patent any part of the design. The ship was designed in Gothenburg, Sweden, in collaboration with Sven Almqvist.

Zoroaster carried 242 tons (246 tonnes) of kerosene (paraffin), which was rapidly taking over from whale oil for lighting. Her success meant that Nobel began to commission bigger ships. However, while her sister ship was in Baku in 1881 taking on kerosene, a squall hit the ship and the oil pipe was jerked away and kerosene spilled. The ship exploded. Nobel reacted to the accident by designing a flexible, leak-proof loading pipe. In 1883, an employee produced a new tanker design, subdividing their storage space into smaller tanks, so minimizing the *free surface effect* where oil sloshing from side to side could cause a capsize. The first American oil tank steamship was built following Nobel's drawings and calculations, shortly after his death. Petroleum oil is not just fuel for cars, trucks, ships and planes but also the raw material for many chemical products, including pharmaceuticals, solvents, fertilizers, pesticides, clothing and plastics.

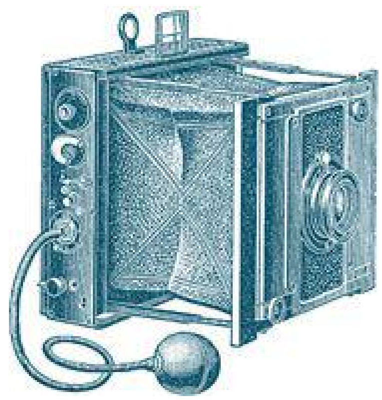
MOTION PICTURES

—– 1879 —–

EADWEARD JAMES MUYBRIDGE 1830–1904, ENGLAND AND UNITED STATES

Muybridge's *zoopraxiscope* projected motion pictures, predating the flexible perforated film strip, and inspired Edison and others to develop the moving film camera. Emigrating from England to the United States, Muybridge (born Edward James Muggeridge) worked as a bookseller before taking up photography aged 37. By the time he was 42, Muybridge was the top photographer on the West Coast and was gaining an international reputation. Amasa Leland Stanford (1824–1893) was an industrialist, tycoon, politician, former governor of California, future senator for California and the founder of Stanford University. Stanford commissioned Muybridge to use photographic technology to establish whether a trotting horse ever has all four feet off the ground simultaneously. Stanford wanted hard evidence and offered Muybridge $2000 to produce it, but Muybridge knew the limitations of photographic technology. Cameras and the film of the day were not suited to capturing motion, which usually showed up as a blur. The shutters were too slow, and although mechanical

shutters were becoming available, most photographers relied on the lens cap, a board or even a hat, anything that could be used to manually cover and uncover the lens. As for film, photographers made their own on the spot by pouring a messy solution known as *wet collodion* onto a glass plate, then priming the plate in a solution of silver nitrate. The concoction was more than 300 times less lightsensitive than modern film. One manual advised that '*the time of exposure in the camera is entirely a matter of judgment and experience,*' adding that on bright days, '*from fifteen seconds to one minute will answer*'. However, to establish the movements of a horse moving at around 40 feet (12 m) per second was impossible unless pictures were taken in a fraction of a second. It took five years to get a shot of a running horse that Muybridge considered satisfactory.



In 1872 Muybridge used a battery of 24 cameras to photograph the motion of a trotting horse owned by Stanford. The resulting 24 pictures taken as the horse raced past signalled the beginning of what would become known as 'stop-action series photography'. The *New York Times* reported in May 1873 that '*A San Francisco photographer is declared to have obtained a perfect likeness of the horse Occident going at full speed.*' No one had ever seen anything like this before, and this illustration of motion through a series of still images viewed in rapid sequence was a forerunner of motion picture technology. In 1874 Muybridge rigged his cameras to photograph in stop-action again, a series of pictures which showed that, in fact, the four hooves of a horse did at one point all leave the ground at the same time. The cameras had been set along the track with triggered shutters set at appropriate intervals. The horse was 40 feet (12 m) from the camera and the exposure was 1/1000th of a second. The exposure was triggered electromagnetically using wires across the track. This event has gone down

in history as one of the most important moments in the story of moving picture development. The series was published later in 1881 under the title *Attitudes of Animals in Motion*, and a patent was later granted for this method of stop-action series photography in 1897.

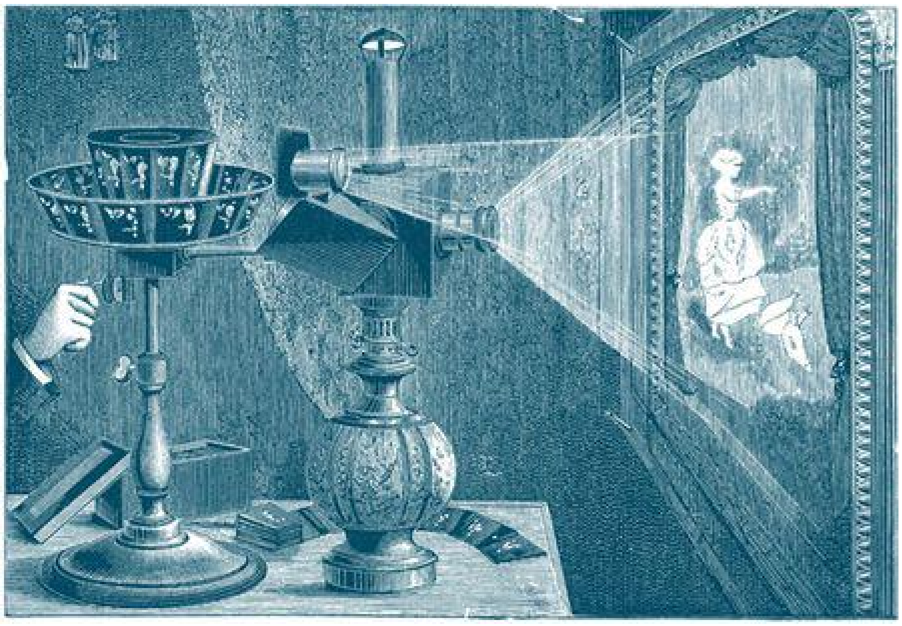
THE PHOTO-FINISH

IN MAY 1882 Muybridge asserted in *Nature* regarding horse races, that '*no race of any importance will be undertaken without the assistance of photography to determine the winner … In an important race the decision of the camera would be preferred to that of the judges.*' In 1888 Ernest Marks, official photographer for the Plainfield Racing Association in New Jersey, provided positive photographs within three minutes of the finish of a disputed race. That picture does not survive, the earliest extant being from 25 June 1890 at the Sheepshead Bay Race Track in Brooklyn, New York.

In 1874 Muybridge discovered his wife had been adulterous with a younger man, Harry Larkyns. Muybridge collapsed and wept, according to a nurse who was present when he found out the news. That night Muybridge tracked Larkyns to a house near Calistoga and shot him through the heart. At his murder trial in 1875, the jury rejected an insanity plea but accepted the defence of justifiable homicide, finding Muybridge not guilty of murder. After the acquittal, Muybridge sailed for Central America and spent the next year in 'working exile'. In 1879 the *zoopraxiscope*, a moving picture projector, was designed and introduced by Muybridge. Film historians consider the zoopraxiscope a forerunner of the movie projector because it showed the first images based on action photos and, unlike the *zoetrope*, projected those images so that many people could watch at once. Muybridge reserved the premiere of the zoopraxiscope for his patron, showing the world's first 'movie' to the Stanfords and a few friends. After a public showing in San Francisco the following spring, a newspaper reporter rhapsodized: '*Nothing was wanting but the clatter of hoofs upon the turf and the occasional breath of steam to make the spectator believe he had before him the flesh and blood steeds.*'

The university of Pennsylvania granted Muybridge funds of $5000 to advance his research in stop-action series photography. Between the years 1883–5 Muybridge took more than 100,000 photographs, which were

published in 1887. From this point on, Muybridge's work began to show that the possibility of actual moving pictures or ciné-photography was a reality and not far from perfection. Muybridge's photographs are the world's first motion pictures. In 1883 and 1888 Muybridge met Edison to propose a combination of Muybridge's zoopraxiscope for vision, and Edison's phonograph for audio, thereby providing the initial steps needed to produce a complete episode of natural motion with sound.



FINGERPRINTING

—— 1880 ——

HENRY FAULDS 1843–1930, SCOTLAND

A Scottish missionary in Japan, Faulds founded a hospital in Tokyo and became a surgeon. Fluent in Japanese, he established the Tokyo Institute for the Blind. In the late 1870s he was involved in archaeological digs in Japan. He noticed the potters' fingerprints on shards of ancient pottery, and began to extend his study to modern fingerprints, writing to Charles Darwin about his ideas. In 1880 Faulds published a paper in *Nature* magazine on fingerprints, observing that they could be used to catch criminals and suggesting how impressions could be made with printing ink. In 1886 Faulds returned to Britain and became a police surgeon in Staffordshire. He offered his fingerprinting system to Scotland Yard, which declined the offer.

Faulds died aged 86, bitter at the lack of recognition he had received for his work. Darwin had passed Faulds's letter to his cousin, Francis Galton, who after ten years' research published a detailed statistical model of fingerprint analysis and identification, encouraging its use in forensic science. Galton calculated that the chance of a *false positive* (two different individuals having the same fingerprints) was about 1 in 64 billion. Fingerprinting has served all governments worldwide during the past 100 years or so by providing accurate identification of criminals. No two fingerprints have ever been found identical in many billions of human and automated computer comparisons.

FINGERPRINT MUTILATION

THE NOTORIOUS American bank robber John Dillinger (1903–1934) burned his fingertips with acid to avoid being identified by their ridge patterns. However, prints taken on his death showed that the ridge patterns which grew back were identical to his previous fingerprints. The first case of documented fingerprint mutilation also occurred in 1934. Theodore 'Handsome Jack' Klutas was head of a gang known as the College Kidnappers. When the police finally caught up with him, Klutas went for his gun, and the police returned fire, killing him. When they compared his postmortem fingerprints, police found that each of his digits had been cut by a knife, resulting in semicircular scars around each fingerprint. Although he was glorified in the media, it was an amateur job; the procedure left

more than enough ridge detail to identify him. In 1941 another American criminal named Roscoe Pitts had a plastic surgeon remove the skin from the first joints of his fingers, and replace it with skin grafts from his chest. Investigators were still able to identify him from his ‘new’ fingerprints and his palm print.

THE CASE OF THE MISSING FINGERPRINTS

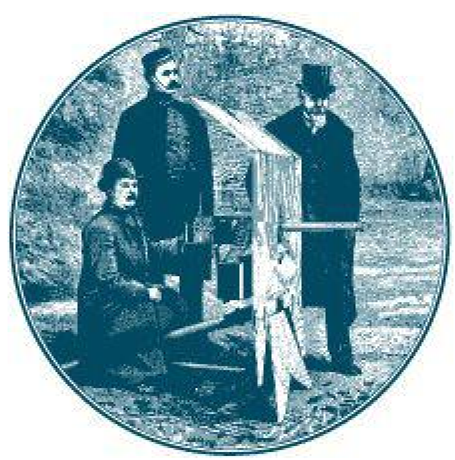
THE MAY 2009 issue of the *Annals of Oncology* reported (online) that a 62-year-old man from Singapore was detained while travelling to the United States, because a routine fingerprint scan showed that he actually had none. He had been taking the chemotherapy drug capecitabine (brand name Xeloda) to keep head and neck cancer in check. The medication gave him a moderate case of hand–foot syndrome (also called chemotherapy-induced acral erythema), which can cause swelling, pain and peeling on the palms and soles of the feet – and, apparently, loss of fingerprints. His physician, who authored the report, found informal online reports of other chemotherapy patients complaining of lost fingerprints. Other diseases, rashes etc. can have the same effect, but usually our skin regenerates quite quickly, so unless permanent damage is done to the tissue, it will regrow. The people who most often lose their fingerprints seem to be bricklayers (and some tilers and roofers), who wear down print ridges by handling rough, heavy materials, as well as people who work with lime (calcium oxide), because it dissolves the layers of the skin. Even secretaries may also have their prints obliterated, because they deal with paper all day. The constant handling of paper tends to wear down the ridge detail. Professional harpists and, curiously, bakers are other occupations who may lose fingerprint definition. The elasticity of skin decreases with age, so many senior citizens have prints that are difficult to capture. The ridges get thicker, and the height between the top of the ridge and the bottom of the furrow gets narrow, so there is less prominence.

AUTOMATIC MACHINE GUN

—— 1883 ——

Hiram Stevens Maxim 1840–1916, United States and England

Maxim’s machine gun is often identified as the weapon most associated with British imperial conquest, and it was used by all sides in the carnage of the First World War. Born in the United States, Maxim emigrated to England aged 41 and took English citizenship. He invented the first self-powered portable machine gun, the Maxim gun, patenting it in 1883. It used an action that would close the breech and compress a spring. The energy stored from the recoil that ejected each spent cartridge case was used to insert the next one. This made it much more efficient and less labourintensive than previous rapid-firing guns, such as the Gatling gun, which relied on actual mechanical cranking. During trials in 1884 it was demonstrated that this new ‘automatic’ Maxim could fire 600 rounds per minute, equivalent to the firepower of about 30 contemporary breech-loading bolt-action rifles.



Maxim founded an armaments company to produce his machine gun which later merged to form Vickers, Son & Maxim in 1896. A prototype of the Maxim gun was used by Henry Morton Stanley's relief expedition to the Emin Pasha in 1886–90, and it was also instrumental in the establishment of a British protectorate over Buganda (modern Uganda). It was also used in Singapore in 1889, and in the First Matabele War (1893–4). In this war, at the Battle of Shangani, 50 soldiers with four Maxim guns fought off 5000 warriors. The gun was extensively employed in the European take-over of several African kingdoms. The updated design of the Maxim gun, now called the *Vickers gun*, was the standard British machine gun in the First World War, and for many years afterwards. Variants were used extensively by both sides during this war, the Russian and German versions being almost replicas. Compared to modern machine guns, the Maxim was heavy, bulky and awkward to operate. Although a lone soldier could fire the weapon, it was usually served by a team of men. Several men were needed to move or shift its position on a tripod, and cooling the barrel of the gun required a constant supply of water in order to allow an uninterrupted stream of fire. Moronic infantry commanders in this war ordered British troops to walk towards German entrenchments guarded by entanglements of barbed wire, rather than run and duck and weave, as it was poor discipline not to advance in an orderly fashion. Hundreds of thousands of men were thus cut to pieces by German copies of the Vickers (Maxim) gun.

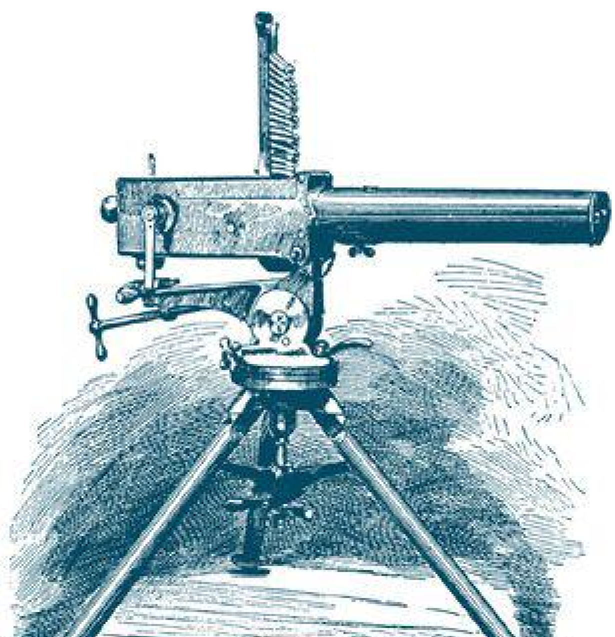
MAXIM'S FLYING MACHINE

MAXIM DISCOVERED a technique for creating a high-quality filament for the electric light bulb, but Edison copied his idea (this is a thread running through this book), and Maxim never forgave him for taking the credit for the design for electric lighting. Maxim also never patented his automatically resetting mousetrap nor his automatic fire alarm system. In the early 1890s Maxim was in a position to begin work on the creation of a manned flying machine. He predicted with great prescience that, once this was achieved, '*Within a few years, someone – if not myself, someone else – will have made a machine which can be guided through the air, will travel with considerable velocity and will be sufficiently under control to be used for military purposes*'. On 31 July 1894 he gave the first public demonstration of the flying machine, improving the spectacle by extending the length of

the guide rails, and by piloting the machine himself. The craft broke free of the rails and briefly achieved free flight. Despite the crew being thrown off their feet, Maxim was able to shut off the power, and the machine crashed back to the ground, causing substantial damage. Maxim could now claim, with some justification, that he was the designer of the first machine to take off unaided (i.e. without the use of ramps or other accessories), and achieve self-powered free flight.

MAXIM ON FRICTION

'*BUT AS no two* [theoreticians] *agree on this* [skin friction on flying machines] *or any other subject, some not agreeing today with what they wrote a year ago, I think we might put down all their results, add them together, and then divide by the number of mathematicians, and thus find the average coefficient of error.*' Sir Hiram Maxim in *Artificial and Natural Flight*, 1908



SKYSCRAPER

—— 1884–1885 ——

WILLIAM LEBARON JENNEY 1832–1907 AND GEORGE A. FULLER 1851–1900, UNITED STATES

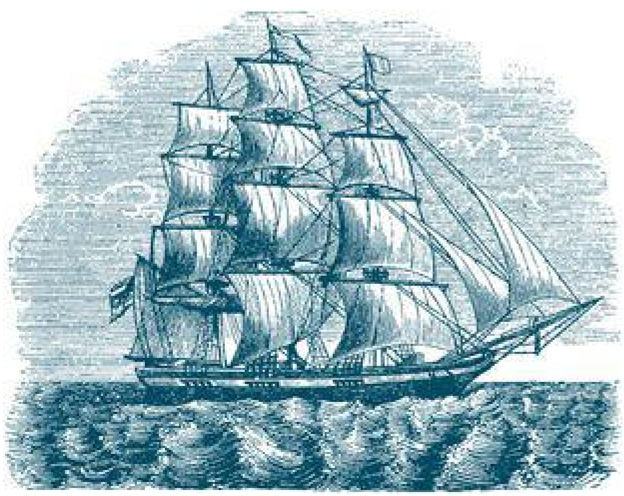
With the invention of the skyscraper, the existing limits on the heights of buildings were removed, allowing more efficient and economic use of space. Organizations could now centralize their operations in one large edifice. In effect, the Henry Bessemer patent of '*a decarbonization process, utilizing a blast of air*' gave us the modern steel industry, enabling new building techniques. Throughout history, the weight of a multi-storey building had to be supported principally by the strength of its walls. The taller the building, the more strain this placed on its lower sections. There were thus engineering limits to the weight such *load-bearing* walls could sustain, and large designs meant massively thick walls on the ground floors, which imposed definite limits on the building's height. The development of cheap, versatile steel in the second half of the 19th century changed those rules for architects and builders. A much more urbanized society was forming which needed new, larger buildings. The mass production of steel was the main driving force behind the movement to build skyscrapers during the mid 1880s. The price of a ton of steel at Bessemer Steel Rails dropped every year from 1867 to 1895, falling from $166 to $32. By assembling a framework of steel girders, engineers could create tall, slender buildings with a strong and relatively delicate steel skeleton. The other elements of the building, the walls, floors, ceilings and windows, were suspended from the steel, which carried their weight. This new *column-frame* construction pushed buildings upwards rather than outwards. The steel weight-bearing frame allowed not just taller buildings, but permitted much larger windows, which meant more daylight reaching interior spaces. Interior walls also became thinner, as they were not load-bearing, which created more usable floor space. Combining innovations such as steel structures, lifts, central heating, electrical plumbing pumps and the telephone, skyscrapers came to dominate American skylines at the end of the 19th century. Their invention is attributed to several architects.

SKYSCRAPERS AT SEA

THE TERM ‘skyscraper’ was first applied to buildings of steel-framed construction of at least ten storeys in the late 19th century, a result of the public amazement at the tall buildings being built in major cities like Chicago, Detroit, St Louis and New York. The 18th-century origin of this building term was a small, triangular sail set above the sky sail on the old squarerigged sailing ships, to try and catch more wind in areas of calm air. They were said to ‘*scrape the sky*’. It was later used to describe a tall person, then a tall building for the first time in the 1880s. Other names for the different types of the very highest sails used on ships were *moonrakers*, *moonsails, angel’s foot stools, kites, stargazers, royals* and *topgallant studding sails*. They were only used in times of dead calm, and never in strong winds as they would rip away.

The fifth verse of the traditional sea shanty *The Flash Frigate* is:

‘*The next thing we hear is “All hands to make sail!”*
“Way aloft!” and “Let out!” and “Let fall!” is the hail,
Oh, your royals and your skysails and your moonsails so high,
At the sound of the call your skyscrapers must fly.’



An early development was Liverpool’s *Oriel Chambers* of 1864, designed by Peter Ellis. It was the world’s first iron-framed, glass-curtain-walled office building. It was only five floors high. Further developments led to what is regarded as the world’s first ‘skyscraper’, the ten-storey *Home Insurance Building* in Chicago (1884–5). Its architect, William LeBaron Jenney, created a load-bearing structural frame for it and this steel frame supported much of the weight of the stone walls, instead of load-

bearing walls carrying the weight of the building. This development led to the *Chicago skeleton* form of construction. It was the first fully metalframed building, using metal columns and beams instead of stone and brick to support the building's upper levels. The steel needed to support the Home Insurance Building weighed only a third as much as an equivalent building made of heavy masonry. Because the weight of the building was reduced, it was possible to construct even taller structures. Later, Jenney solved the problem of fireproof construction for tall buildings by using masonry, iron and terracotta flooring and partitions, instead of wood.

George Fuller worked on solving the problems of the load-bearing capacities of tall buildings. He built the *Tacoma Building* in Chicago in 1889, the first structure ever built in which the outside walls did not carry any of the weight of the building. Using Bessemer steel beams, Fuller created steel cages that supported all the weight in a tall building. In 1892 New York City altered its building regulations to allow 'skeleton construction and curtain', in which the load created by the building was carried by the internal skeleton and not by the exterior wall, a construction method which had been allowed under the Chicago building code for years. This change prompted George Fuller to open an office in New York in 1896. The landmark *Flatiron Building* was one of New York City's first skyscrapers, built in 1902 by Fuller's building company. Most early skyscrapers emerged in the land-strapped areas of Chicago, London and New York towards the end of the 19th century. Today's giant skyscrapers are built almost entirely of reinforced concrete. The tallest skyscraper under development is Kingdom Tower, which has recently been announced as part of the development of *Kingdom City*, marking '*the gateway to Mecca*'. The

Saudi Binladin group will build the megastructure for Prince Alwaleed bin Talal in Jeddah, close to the Red Sea. It is planned to be 3281 feet (1000 m) tall.

HIGH SPEED PETROL ENGINE AND FOUR-WHEEL AUTOMOBILE

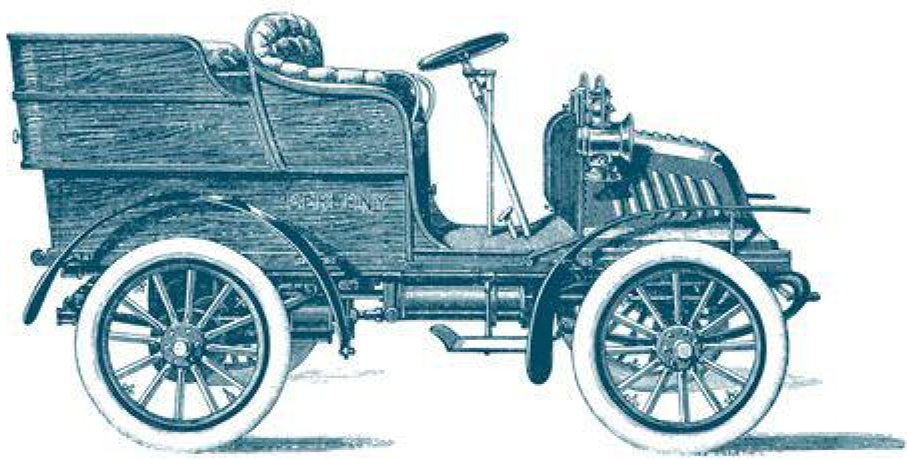
—— 1885 *and* 1887 ——

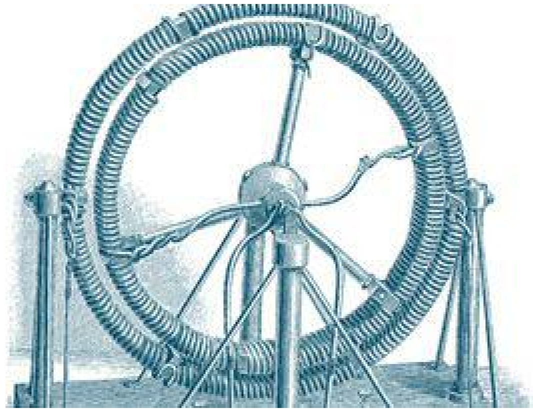
GOTTLIEB WILHELM DAIMLER 1834–1900 AND WILHELM MAYBACH 1846–1929, GERMANY

Daimler was a workshop manager with Nikolaus August Otto, the inventor of the four-cycle internal combustion engine. Maybach was a designer of stationary engines, who became Daimler's lifelong collaborator. In 1882 Daimler and Maybach set up a factory to produce a light, high-speed, petrol-powered internal combustion engine. They wanted the engine to be able to power vehicles. Daimler invented a reliable self-firing ignition system, consisting of a red-hot porcelain tube that protruded into the cylinder. Maybach patented a device similar to the carburettor to make their engine more fuel-efficient. The engine's small size and these associated developments helped to push them ahead of other inventors who were emerging as competitors. The pair now concentrated upon designing and building light, high speed internal combustion engines suitable for land, air or sea transport.

In 1885 they designed and patented a precursor of the modern petrol (gasoline) engine, which they then fitted to a twowheeler, the first powered motorcycle. Their new engine was also fitted to a stagecoach and a boat. In 1887 this innovative air-cooled engine was adapted to power a four-wheeled vehicle, creating one of the first true automobiles. Its unique features included a belt-drive mechanism to turn the wheels, a *tiller* for steering, and a four-speed gearbox. After spending many hours debating which fuel was best to use in Otto's original four-stroke engine, which had normally used methane gas, they decided to use petroleum. Up until that time petrol was used mainly as a cleaner and sold in pharmacies. At the 1889 Paris Exposition they exhibited a two-cylinder V-shaped engine, perhaps the first engine to use the 'V' design. The innovative engine was now installed in a commercially feasible four-wheeled automobile. In 1890

Daimler and Maybach formed the Daimler Motor Company, but they left the company in 1891 to concentrate on various technical and commercial development projects. A Daimlerpowered car won the first international car race, the 1894 Paris-to-Rouen. Of the 102 cars that started the competition, only 15 completed it, and all finishers were powered by a Daimler engine. The race helped to promote the concept of motoring in general, and Daimler and Maybach rejoined the Daimler Motor Company in 1895. In 1896 Daimler produced the first road lorry. In 1899 it produced the first Mercedes automobile (named for the daughter of the financier Emil Jellinek who was backing Daimler), and in 1926 merged with the company founded by Karl Benz to become Mercedes-Benz. Daimler and Maybach were the pioneers of all road transport using petrol.





CHAPTER 7

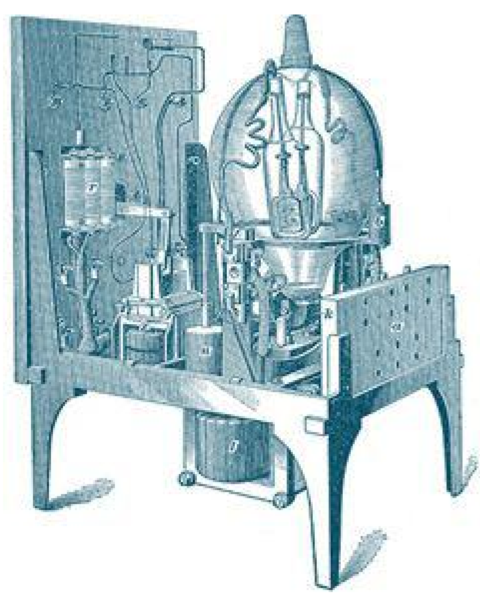
THE ELECTRIC AGE

POLYPHASE ALTERNATING CURRENT SYSTEM

—— 1888 ——

NIKOLA TESLA 1856–1943, AUSTRIAN EMPIRE (MODERN CROATIA), AND UNITED STATES

Tesla was an electrical engineering genius who worked on improving Edison's range of dynamos, while employed at Edison's lab in New Jersey. Tesla's imagination enabled him both to develop scientific hypotheses and to put them into practice. Tesla pointed out the inefficiency of Edison's direct current (DC) electrical power stations that had been built along the Atlantic seaboard. Edison's lamps were weak and inefficient, and the system had a severe disadvantage in that power could not be transmitted more than two miles (3.2 km) due to its inability to step up to high voltage levels necessary for long-distance transmission. Thus, a new direct current power station was required at two-mile intervals. The secret, Tesla felt, lay in the use of alternating current (AC), because to him all energies were cyclic. He left Edison's company and by February 1882 had discovered the rotating magnetic field, a fundamental principle in physics and the basis of nearly all devices that use alternating current. Tesla adapted the principle of a rotating magnetic field for the construction of an alternating current induction motor and the polyphase system for the generation, transmission, distribution and use of electrical power.



Tesla introduced his motors and electrical systems in his paper, *A New System of Alternating Current Motors and Transformers*, which was delivered to the American Institute of Electrical Engineers in 1888. George Westinghouse, founder of the Westinghouse Electric Company, then bought the patent rights to Tesla's system of alternating current, which eventually killed off Edison's direct current technology. Tesla next astonished the world by demonstrating the miracle of alternating current electricity at the World Columbian Exposition in Chicago in 1893. Alternating current became the standard electrical power supply of the 20th century, Tesla's accomplishment changing the world. He designed the first hydroelectric power plant in Niagara Falls in 1895, which marked the final victory for alternating current. Tesla also developed new types of generators and transformers, a system of alternating current power transmission, fluorescent lights, X-rays and a new type of steam turbine. He ran out of funds to develop a wireless broadcasting company, but scientists still scour his notebooks for new ideas. Tesla's AC induction motor is widely used throughout the world in industry and household appliances. Electricity today is generated, transmitted and converted to mechanical power by means of his inventions. Tesla lit up the globe and accelerated the Industrial Revolution. Nikola Tesla's name has been honoured with an International Unit of Magnetic Flux Density being called a *Tesla*. His contributions to science were summed up by Ben Johnston in the 1983 *Introduction to My Inventions: The Autobiography of Nikola Tesla*: '*Nikola Tesla is the true unsung prophet of the electronic age; without whom our radio, auto ignition, telephone, alternating current power generation and transmission, radio and television would all have been impossible.*'

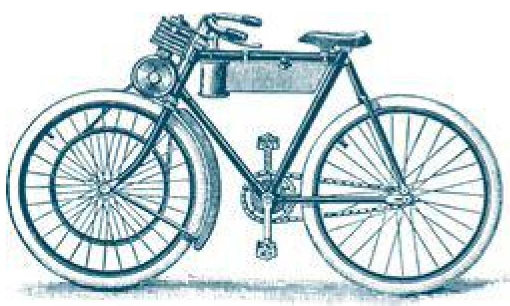
PNEUMATIC TYRE

—— 1888 ——

JOHN BOYD DUNLOP 1840–1921, SCOTLAND

A Scottish veterinary surgeon, Dunlop did not actually invent this device. It was first conceived by another Scotsman, Robert William Thomson, in the 1840s, but Dunlop was the first to develop and patent a usable practical version of it. In 1888 he was watching his son ride his tricycle, and noticed that the child was encountering difficulty and discomfort while riding over

cobbled ground. Dunlop realized that this was because of the vehicle's solid rubber tyres, and he began looking for a way to improve them. The solution he came up with was a rubber tube filled with air to give it cushioning properties. Dunlop patented the design and soon bicycle and automobile manufacturers recognized its potential usefulness. Dunlop's development of the pneumatic tyre came at a crucial time in the development of road transportation. Commercial production began in 1890 in Belfast, and within ten years of patenting the device, it had almost entirely replaced solid tyres. Through the company he founded, Dunlop Tyres (now a subsidiary of Goodyear), his name is still associated with the automobile industry. In 1891 the Michelin brothers patented a removable pneumatic tyre, which was used to win the world's first long-distance cycle race, Paris–Brest–Paris. In 1895 André Michelin was the first person to fit pneumatic tyres to an automobile. In 1903 Goodyear Tyre Company patented the first tubeless tyre, but it was not introduced until 1954 on Packard cars. Philip Strauss invented the first practical tyre in 1911, with an air filled inner tube and a rubber tyre outside, which was quickly adopted by bicycle manufacturers.



THE FORGOTTEN INVENTOR

ROBERT WILLIAM THOMSON (1822–1873) was only 23 when in 1845 he applied for the patent that would leave his mark on the world – Patent No 10990. The pneumatic rubber tyre – or *aerial wheel* as Thomson referred to it – would eventually transform road travel. Despite its demonstrable advantages, Thomson's invention was 50 years ahead of its time, as not only were there no motor cars, but bicycles were only just beginning to appear. This lack of demand, together with the high production costs, rendered pneumatic tyres a mere curiosity. Undeterred, Thomson patented the principle of the self-filling fountain pen in 1849. In 1891, years after

Thomson’s death, Dunlop’s tyre patent was invalidated in favour of Thomson’s.

CINEMATOGRAPHY

—— 1888 ——

WILLIAM EDWARD FRIESE-GREENE 1855–1921, ENGLAND, AND LOUIS AIMÉ AUGUSTIN LE PRINCE 1841–1890, FRANCE AND ENGLAND

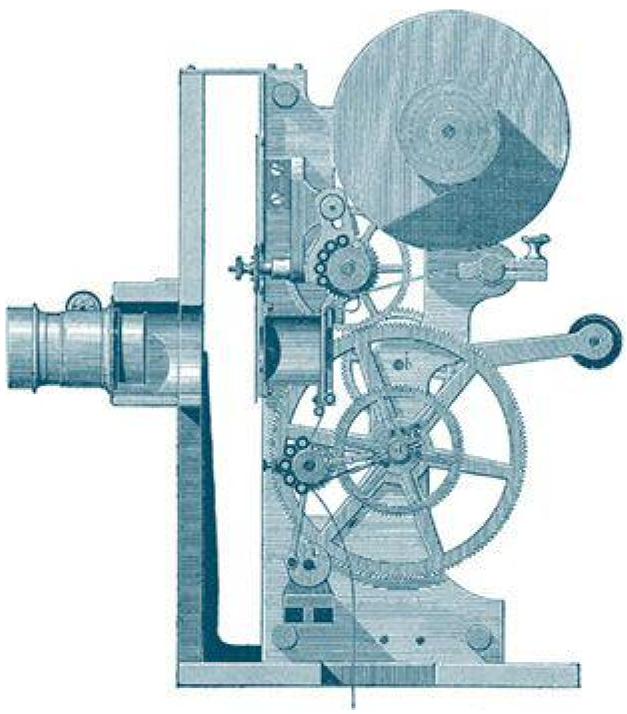
Both of these men can be credited with pioneering the moving film industry. The story of the development of early cinema is intriguing, with several claimants to its invention. In Highgate Cemetery there is a memorial designed by Edwin Lutyens commemorating William Friese-Greene as ‘*the inventor of Kinematography*’. Friese-Greene was an inventor and portrait photographer. Working in Bath, he met John Arthur Roebuck Rudge (1837–1903), who had begun to make ‘*magic lanterns*’. Rudge had developed a unique ‘*Biophantic Lantern*’, or ‘*Phantascope*’, which could display seven slides in rapid succession, giving the illusion of movement. From 1886 Friese-Greene began to work with Rudge so that the machine could project photographic plates. They called their device the *Biophantascope*. Friese-Greene realized that glass photographic plates would never be a practical medium for moving pictures, and began to experiment with oiled paper.

In 1887 he was the first person to experiment with the new material of celluloid as a medium for motion picture cameras. Friese-Greene worked upon synchronizing Edison’s new phonograph with a projector that he was working on. He wrote to Edison but received no response. However, Edison also began working in this area. Friese-Greene’s papers quote him as

writing: '*Why should not moving pictures be combined with records of other sounds – all sounds, speech, traffic, the thud of horses' feet on the turf, the striking of the ball on bat at a cricket match, the sounds of human speech? Synchronization of sound and sight is surely only a matter of improvement in mechanism.*' In 1889 Friese-Greene presented a short film using celluloid film made with his *cinematographic camera* which shot five frames per second. He applied for a British patent for it, issued in 1891, calling it an '*Improved apparatus for taking photographs in rapid series*'. An article appeared in the *Optical Magic Lantern Journal and Photographic Enlarger* of 1891 describing the apparatus: '*This instrument is pointed at a particular object and by turning the handle several photographs are taken each second. These are converted into transparencies, and placed in succession upon a long strip, which is wound on rollers and passed through a lantern of peculiar construction (also the invention of Mr. Friese-Greene), and by its agency projected upon a screen. When the reproduction of speech is desired this instrument is used in conjunction with the phonograph.*'

On 21 June 1889 Friese-Greene was issued with a patent for his innovative *chronophotographic* camera, capable of taking up to ten photographs per second, using perforated celluloid film. A report about his new camera was published in the *British Photographic News* in February 1890. In March of that year Friese-Greene again wrote to Edison, enclosing a clipping of the story, for whom William Dickson had just begun to develop a motion picture system known as the *Kinetoscope*, and the report on Friese-Greene's invention was featured in the *Scientific American* in April. Friese-Greene next gave a public demonstration in 1890 but the low frame rate and his new machine's mechanical unreliability did not attract financial backing. In the early 1890s he experimented with cameras to create stereoscopic moving images, but he had exhausted all his financial resources, and was declared bankrupt in 1891. To cover his debts he sold the rights to the chronophotographic camera patent for £500. The renewal fee was never paid and the patent eventually lapsed. Friese-Greene then developed the *Biocolour system* for colour in motion pictures, but the owners of a rival system known as *Kinemacolor* claimed that the new colour film was an infringement of their patent. Friese-Greene counterclaimed that their patent did not contain enough detail to encompass the Biocolour process. The judge ruled in Kinemacolor's favour, but in 1914 the House of Lords reversed the decision. However, Friese-Greene's

system was still in its infancy and he was unable to exploit this success. The *Kinetoscope* of William Dickson and Edison was developed between 1889 and 1892, its idea being inspired by Eadweard Muybridge's 1883 and 1888 meetings with Edison. Muybridge later described how he proposed a collaboration in order to combine his device with the Edison phonograph, a system that would play sound and images concurrently. In October 1888 Edison filed a preliminary patent claim, known as a caveat, announcing his plans to create a device that would do '*for the Eye what the phonograph does for the Ear*'. Much of Edison's work of this time has been a source of considerable controversy. As with many of Edison's 'inventions', elements of truth have been deliberately obscured in order to achieve business success.



Louis Le Prince was a French scientist and inventor, and he is considered by many film historians to be the true father of motion pictures. He shot the first moving pictures on paper film using a single lens camera. After initial work on motion picture experiments, in 1886 he applied for a patent for the production of animated pictures. Le Prince conducted his ground-breaking work in Leeds in October 1888, filming moving picture sequences in Roundhay Gardens and a street scene on Leeds Bridge. These pictures were later projected on a screen in Leeds, making it the first motion picture

exhibition. No other strip of film has ever been produced which predates the *Roundhay Garden Scene* which was photographed using his 16-lens camera at 16 frames per second, using non-perforated sensitized Eastman Kodak film-paper. His films are the most important cinematic events simply because they are the first ever made using a continuous strip (paper or celluloid) of individually photographed frames that were projected in sequence providing fluid motion.

OTHER PIONEERS OF THE SILVER SCREEN

FOR THE April 1894 commercial exploitation of his personal *Kinetoscope Parlor*, Thomas Edison is credited as the inventor of cinema, but his employee William Kennedy Laurie Dickson (1860–1935) headed the team that developed the *Kinetograph* and *Kinetoscope*. In 1894 Dickson used the Kinetograph to photograph Fred Ott, one of Edison's laboratory workers, standing in front of the camera sneezing. This was a publicity stunt for a New York magazine, which wanted still pictures of a man sneezing to accompany a story. It was catalogued as *Edison Kinetoscopic Record of a Sneeze*. Its four seconds have become famous now as *Fred Ott's Sneeze*. The footage was copyrighted by Dickson and cameraman William Heise (another Edison employee) as a 'photograph' with the Library of Congress in January (it was actually a proof sheet containing 45 images). It was photographed at 16fps on 35mm film stock.

In France the Lumière brothers are acknowledged as inventors of the *Cinématographe* device and thus inventors of cinema for the first, collective, commercial exploitation of motion picture films in Paris. In fact, the French inventor Léon Bouly created the first *Cinématographe* device and patented it in 1892. Two years passed, however, and he had not paid a patent fee, so the patent was bought by the Lumière brothers. In 1894 Charles Francis Jenkins (1867–1934) produced the first motion picture projector using reeled film and electric light, the *Phantascope*. This *Phantascope* was actually the work of John Arthur Roebuck in 1889, but was perfected by Jenkins with the addition of roll film and electricity. It was the first motion picture that worked in colour. Jenkins sold the rights, which were acquired by Edison who renamed it the *Vitascope*. Jenkins went on to become a pioneer in developing televisual technology. In 1928 his Jenkins Television Corporation opened the first television broadcasting station in

the USA, named W3XK. It went on air on 2 July and first broadcast, initially in silhouette only, from the Jenkins Labs in Washington D.C. and from 1929 from Wheaton, Maryland, on five nights a week.

The early history of motion pictures in the United States and Europe is littered with battles over camera patents. In 1888 Le Prince filed a patented in the USA for a camera and projector described as having 16 lenses (however his application describes '*one or more lenses*'). As he realized that he was close to being the first person to project moving pictures publicly, Le Prince also applied for international patents in Belgium, Italy, Austria, Hungary, France and in England. But he would never live to see them granted. His British patent described the use of flexible film (positive and negative) and intermittent movement in the shutter. His apparatus was capable of showing animated pictures, which he had already presented in the Whitley factory in Leeds. His application for a patent for a singlelens type movie camera was refused in America because of an interfering patent. However, a few years later the same patent was not opposed when the Edison company applied for one. In 1889 Le Prince used sensitized roll celluloid in his *Cinematograph*. In 1889 Le Prince took French-American dual citizenship in order to establish himself with his family in New York in order to follow up his research. Tragically, he was never able to perform his planned public exhibition at Jumel Mansion, New York, in September 1890. On 16 September, while on a visit to his native France, Le Prince apparently boarded a train at Dijon. He had promised friends that he would rejoin them in Paris on the following Monday for the return journey to the UK, to be followed by his trip to the USA to promote his new camera. He vanished from the train and was never seen again by his family or friends.

Various theories have been proposed to account for his disappearance, including suicide and murder. In his 1990 book *The Missing Reel*, historian Christopher Rawlence discusses an assassination theory to explain the disappearance. He describes the Le Prince family's suspicions of Edison with regard to patents. At the time that he vanished, Le Prince was about to patent his 1889 projector in the UK and then leave Europe for his scheduled New York official exhibition. His widow assumed foul play. After his disappearance, the Le Prince family led by his wife and eldest son Adolphe went to court to file an action against Edison in what became known as Equity 6928. In 1898 Le Prince's son Adolphe, who had assisted his father

in many of his experiments, was called as a witness for the American Mutoscope Company in their litigation with Edison [Equity 6928]. By citing Le Prince's achievements, Mutoscope hoped to annul Edison's subsequent claims to have invented the moving picture camera. The case went against Mutoscope and the famous 'Patent Wars' ensued. However, by 1908 Thomas Edison was named sole inventor of motion pictures, in the USA at least. In 1902 Adolphe Le Prince was found shot dead on Fire Island, New York. Le Prince's apparatus was eventually built by Herman Casler and was used in taking pictures. Richard Howells wrote in 2006 that: '*Le Prince had indeed succeeded in making pictures move at least seven years before the Lumière brothers and Thomas Edison, and so suggests a re-writing of the history of early cinema.*'

VIRUSES

—— 1892 ——

DIMITRI IOSIFOVICH IVANOVSKY 1864–1920, RUSSIA

The discovery of viruses was a breakthrough in medicine, bringing microbiology and biochemistry together to determine the cause and transmission of a number of diseases. By the late 1800s scientists had accepted the *Germ Theory of Disease* which argued that infectious disease was caused by micro-organisms. Ivanovsky studied at St Petersburg, investigating a disease affecting tobacco plants known as *wildfire*. He graduated in 1888 after presenting his thesis *On Two Diseases of Tobacco Plants*. In the following year he was asked by the directors of the Russian department of agriculture to study a new tobacco disease, called *tobacco mosaic,* which had afflicted plants in the Crimean region. This disease causes tobacco leaves to have a speckled green and yellow appearance. Ivanovsky crushed the infected leaves (distinguished by their mosaic pattern) into sap, and then forced the sap through a porcelain Chamberland bacterial filter, which was known to remove all bacteria. Despite following this procedure, the filtered sap, when brushed on the leaves of healthy plants, still caused disease. Ivanovsky's 1892 report on the tobacco mosaic disease detailed what he maintained must be an agent smaller than a bacterium. It was the first study in which factual evidence was offered concerning the existence of this new kind of infectious pathogen. Ivanovsky

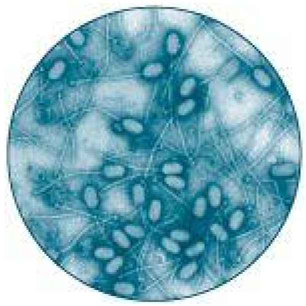
concluded that the cause of the disease was a ‘filterable agent’. The 28-year-old Ivanovsky’s work was ignored by the scientific community, and he eventually abandoned his study of the pathogen without understanding the implications of his research.

The Dutch botanist Martinus Willem Beijerinck (1851–1931) repeated Ivanovsky’s experiments with the new pathogenic source, giving it the name *filterable virus* in 1898. He presented a new idea of an infectious agent. Beijerinck suggested that the disease was caused by a filterable substance which was alive, and could multiply only in living cells. Scientists were for the first time being asked to consider disease agents in chemical, as well as microbiological, terms. In the first 30 years of the 20th century, more than a dozen diseases were credited to this mysterious filterable germ. In 1935 biochemist Wendell M. Stanley (1904–1971) announced that he had crystallized the virus of tobacco mosaic disease. Stanley used techniques developed to crystallize proteins, and showed that viruses could be studied biochemically and microbiologically. Most viruses can only be seen with an electron microscope.

THE DISCOVERY OF THE VIROID AND PRION

IN THE late 1970s a new and even smaller infectious agent was discovered. *Viroids* are small, circular strands of RNA lacking any external covering or protection. Viroids are known to cause disease in at least six plant groups. They have not yet been isolated in animals, but are suspected as being agents of disease. An infectious protein called a *prion* has also been discovered. It lacks nucleic acid, and its method of replication is still unknown. It can cause some diseases affecting the central nervous system of both animals and humans. Spongiform encephalopathies, including BSE (Bovine Spongiform Encephalopathy or *mad cow disease*), are spread by a rogue form of prion. The normal form of the prion protein is produced naturally in the brains of all mammals, and is harmless, but altered forms adopt the role of an infectious agent. Like a rotten apple, once inside the brain, the mutant form of prion protein turns normal protein into more copies of the deviant, infectious form. The end result is a characteristic loss of motor coordination, dementia and death, and a brain full of holes, rather like a sponge.

Nobody understands the connection between prions and the particular pattern of symptoms that seem to be associated with them, nor why the brains of infected people or animals become spongy. Extensive research into BSE and its transmitted human equivalent Creutzfeldt-Jakob disease (CJD) continues, and will have repercussions for understanding other brain-wasting diseases, such as Alzheimer's and Parkinson's disease.



Extremely small, simple in structure, and widely distributed, viruses do not qualify as cells. To get an idea of their size, if people were the size of viruses, the entire population of the United States would easily fit on the end of two pencil erasers. However, they affect living cells and thus exist as if they were a bridge between living and non-living organisms. Viruses differ from cellular organisms in many ways. A virus contains only a single type of nucleic acid. Viruses are called *non-cellular infectious agents*, and must use the metabolic machinery of a live host cell to produce more viral particles. A virus has no metabolism of its own, so it can only reproduce after taking over a living cell. Viruses infect all forms of life. Viruses that infect bacteria are called *bacteriophages*, or simply *phages*, and are some of the most intensively studied viruses. More than 1000 plant diseases are known to be caused by viruses. Damage to the cell wall of a plant cell allows plant viruses to enter. Plant viruses may be transferred by contaminated machinery, fungi, pollen, seeds, nematode worms and sucking insects like aphids. Animal and human viruses cause many diseases including measles, the common cold, influenza, smallpox, herpes and AIDS. Evidence now points to certain viral groups as high risk factors in some cancerous conditions. However, other genetic and environmental factors are necessary before a virus can cause human cancer.

Most viruses enter the body through the mouth and nose, or through a break in the skin such as a bite. Viruses then may encounter the body's own

defence mechanism in the shape of phagocytic white blood cells which engulf and digest them. If they avoid capture, they may then cause a special group of proteins to develop. These proteins, called *antibodies*, attack the invading virus and attach themselves to it. The virus is destroyed by the antibody directly or held until it can be surrounded by white blood cells. If a virus does invade a cell, it sets off a chemical alarm. Another group of proteins, called *interferons*, are then produced when a cell is invaded. Interferons are released from infected cells and bind to the membranes of neighbouring cells. The neighbouring cells are now protected from invading viruses. The best way to prevent viral infections is with vaccinations.

MEDICAL RESIDENCY

—— 1893 ——

WILLIAM OSLER 1849–1919, CANADA

This Canadian physician was also a pathologist, physician, educator, bibliophile, historian and author. In 1889 Osler accepted the position as the first physician-in-chief of the new Johns Hopkins University in Baltimore, Maryland and in 1893 he founded its School of Medicine, becoming its first professor of medicine. The hospital grew more than fivefold during his 16 years of tenure, and his reputation as a clinician, humanitarian and teacher led to his appointment to the Regius Chair of medicine in Oxford in 1905. Osler created the first residency programme for speciality training of physicians, and he was the first to bring medical students out of the lecture hall for bedside clinical training. He insisted that students learned from observing and talking to patients in a *medical residency*. In this stage of medical training, the doctor practises medicine under the careful supervision of fully licensed physicians in a hospital. Osler's innovation spread across the English-speaking world and still applies today in most teaching hospitals. Doctors in training now make up much of a hospital's medical staff, helping to keep care costs down. The success of his residency system depended to a great extent upon its pyramid-like structure with many interns at its base, fewer assistant residents and a single chief resident. (This was in the days before bureaucrats and committee people began to outnumber health professionals in health services across the world).

Osler was fond of saying: ‘*He who studies medicine without books sails an uncharted sea, but he who studies medicine without patients does not go to sea at all.’* His most well-known aphorism was ‘*Listen to your patient, he is telling you the diagnosis*’, which emphasizes the importance of knowing the patient’s history. The contribution to medical education of which he was proudest was his idea of having third- and fourth-year students work with patients on the wards. He pioneered the practice of bedside teaching, making rounds with a handful of students, demonstrating what one student referred to as his method of ‘*incomparably thorough physical examination*’. Soon after arriving in Baltimore Osler insisted that his medical students must attend at bedside early in their training: by their third year they were taking patient histories, performing physicals and doing lab tests examining secretions, blood and excreta. Osler said that he hoped his tombstone would say: ‘*He brought medical students into the wards for bedside teaching … “I desire no other epitaph … than the statement that I taught medical students in the wards, as I regard this as by far the most useful and important work I have been called upon to do.”*’ Osler’s *The Principles of Practice of Medicine* was a key text for both students and doctors, remaining in print across the world until 2001, over eight decades after his death.

OSLER TAKES THE URINE

AT OXFORD UNIVERSITY Osler was lecturing to a room full of medical students and emphasizing the importance of good observation and attention to detail, since careful observations could frequently aid in diagnosis. Sitting in front of Osler was a bottle of urine that was to be analyzed. Pointing out that a diabetic patient’s urine often had sugar in it, he put his index finger into the urine and brought his hand to his mouth to taste the urine. He then passed the bottle around the room and asked the students to replicate what they had seen, in order to test their attention to detail. The students obeyed, each tasting the urine. After the bottle had been returned to him, Osler said, ‘*Now you will understand what I mean when I speak about details, because had you really been watching, you would have seen that I put my index finger into the urine, but my middle finger into my mouth.’*

SILICON CARBIDE (CARBORUNDUM)

— 1893 —

EDWARD GOODRICH ACHESON 1856–1931, UNITED STATES

As a young man, Acheson worked for Thomas Alva Edison, and in 1880 he was experimenting on making a conducting carbon to be used in the new electric light bulb. Acheson left Edison's employment in 1884 to supervise an electric lamp factory, and worked upon the development of artificial diamonds (cubic *zirconium*) in an electric furnace. He heated a mixture of clay and coke in an iron bowl with a carbon arc light and found some shiny, hexagonal crystals (silicon carbide, SiC) attached to the carbon electrode. In 1893 he patented a method for making a new industrial abrasive he called *carborundum* (silicon carbide), by intensively heating a mixture of carbon and clay. In 1896 Acheson was issued a patent for an electrical batch furnace used to produce carborundum, the design of which is used to this day. Carborundum was at that time the hardest man-made surface, and the second hardest surface next to diamond. In 1926 the US Patent Office named it as one of the 22 patents most responsible for the industrial age. The National Inventors Hall of Fame citation noted that '*without carborundum, the mass production manufacturing of precision-ground, interchangeable metal parts would be practically impossible.*'

THE HARDEST ARTIFICIAL SUBSTANCE

A MIXTURE of clay and powdered coke, fused by means of an electrical current, carborundum was for 50 years the hardest known artificial substance in the world, until replaced in some applications by tungsten carbide, boron carbide and artificial diamonds.

Silicon carbide (SiC) powder has been mass-produced as an abrasive since its invention, and used in abrasive machining for applications such as honing, grinding, sand-blasting and water-jet cutting. In the 20th century electronic applications for silicon carbide were found including use in radios, as light emitting diodes (LEDs) and detectors, and today it is widely used in ultra-fast, high-temperature/high-voltage semiconductor electronics. Grains of silicon carbide can be bonded together to form very hard ceramics, which are widely used in applications requiring high endurance, such as car brake discs, car clutches and body armour such as bulletproof

vests. Acheson also discovered that when carborundum was heated to a high temperature, it produced an almost pure form of graphite that could be used as a lubricant. He patented this graphitemaking process in 1896. For the rest of his long life, Acheson researched and patented graphites, industrial abrasives, refractories and processes for the reduction of oxides. Edward Goodrich Acheson was granted 70 patents on devices, techniques and compositions of silicon carbide in the fields of mechanics, electricity, electrochemistry and colloid chemistry. Acheson was also the key figure in successfully establishing at least five industrial corporations dependent on electro-thermal processes.

X-RAYS

—— 1895 ——

WILHELM CONRAD RÖNTGEN 1845–1923, GERMANY

Röntgen is celebrated as the ‘father of diagnostic radiology’, the technique which uses imaging to diagnose disease. In 1869 this German scientist gained a doctorate at the University of Zurich, and from 1875 onwards he held various professorships in physics for the rest of his life. His first work, dealing with the specific heat of gases, was published in 1870 and it was followed by work on the thermal conductivity of crystals. In 1895 he was studying the phenomena accompanying the passage of an electric current through a gas of extremely low pressure. Röntgen enclosed a cathode ray tube in a sealed, thick black carton to exclude all light, which he put in a dark room. A paper plate was covered on one side with barium platinocyanide, and when placed in the path of the rays it became fluorescent, even 6 feet (1.8 m) away from the discharge tube. Röntgen later immobilized the hand of his wife in the path of the rays over a photographic plate. The developed image showed the shadows thrown by the bones of her hand, and the shape of a ring she was wearing. This was surrounded by the penumbra of the flesh, which was more permeable to the rays and therefore threw a fainter shadow. This was the first *röntgenogram* ever taken. Because their nature was then unknown, he gave them the name *X-rays*, not wishing his own name to be used. Later, it was shown that they are electromagnetic rays like light, but they differ from light rays in the higher frequency of their vibration.

On 7 January 1896 the great French mathematician Jules-Henri Poincaré (1854–1912) received a letter containing several photographs of the bones in someone's hand. The bones belonged to Röntgen, and the letter explained that the pictures had been taken the previous month with the aid of a new discovery, X-rays. Röntgen explained that he was publicizing his findings by mailing prints to scientists all over Europe. The photographs created a sensation across the world, and directly led to Henri Becquerel's (1852–1908) discovery of radioactivity in 1896 and also to Marie and Pierre Curie's remarkable work. In January 1896 Eddie McCarthy of Dartmouth, New Hampshire, achieved medical fame when his broken arm was set by physicians using X-rays images of the fracture. This production and detection of electromagnetic radiation, in the wavelength today known as X-rays, earned Röntgen the first Nobel Prize in Physics in 1901. Nikola Tesla also could have a claim to be the first to discover X-rays.

POWERED FLIGHT

—— 1896 ——

WILLIAM (BILL) FROST 1850–1935, WALES

The *Pembrokeshire Herald and General Advertiser* on 11 October 1895 stated that Frost had a provisional patent for his flying machine invention, and had been engaged on the project since 1880, a period of 15 years. His original patent description of 30 August 1895 reads: '… *the flying machine is constructed with an upper and lower chamber of wirework, covered with light waterproof material. Each chamber formed sharp at both ends with parallel sides. The upper large chamber to contain sufficient gas to lift the machine. In the centre of the upper chamber a cylinder is fixed in which a horizontal fan is driven by means of a shaft and bevelled gearing worked*

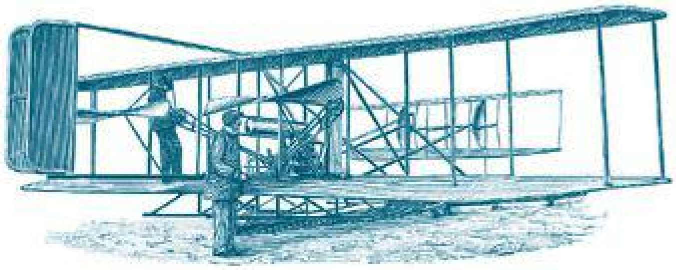
from the lower chamber. When the machine has been risen to a sufficient height, then the fan is stopped and the upper chamber, which has wings attached, is tilted forward causing the machine to move as a bird, onward and downward. When low enough it is again tilted in an opposite direction which causes it to soar onward and upward, when it is again assisted if necessary by the fan. The steering is done by a rudder at both ends.'

INVISIBLE LIGHT

'*In A few minutes there was no doubt about it. Rays were coming from the tube which had a luminescent effect upon the paper. I tried it successfully at greater and greater distances, even at two metres. It seemed at first a new kind of invisible light. It was clearly something new, something unrecorded.'* Quoted by H.J.W. Dam in '*The New Marvel in Photography*', *McClure's Magazine*, April 1896

Upon 26 July 1998 *The Sunday Times* carried a feature '*Welsh airman beat Wrights to the skies*': '*Frost is said to have set off in a "flying machine" from a field in Pembrokeshire and stayed in the air for 10 seconds. Newly discovered documents reveal that Frost, from Saundersfoot, Pembrokeshire, applied to register a patent for his invention – a cross between an airship and a glider – in 1894. It was approved the following year and detailed how the invention was propelled upwards by two reversible fans.*' Frost's flying machine was 31 feet (9.4 m) long and made of bamboo, canvas and wire mesh, with hydrogen-filled pouches to attain 'neutral buoyancy'. It was designed to take to the air by means of a horizontal fan, with the assistance of a cylinder filled with hydrogen. Once in the air the machine would glide for a while on straight wings. When more height was required, the wings would be tilted upwards and the fan used again. Local people insisted that the aircraft was built and flown within a year of the patent being approved. Frost is thus the first pioneer of manned, sustained and powered flight. The historian Roscoe Howells heard an account of the flight from Frost himself: '*His flying machine took off, but the undercarriage caught in the top of a tree and it came down into a field. If he hadn't caught it in the tree, he would have been right over the valley over Saundersfoot and it would have been death or glory.*' Frost's great-greatgranddaughter, Nina Ormonde, stated: '*Our family has always known*

that he was the first to fly, he flew for 500 to 600 yards [over twice the distance of the Wright brothers]. *But Bill gave up on it and there is no point in our revelling in the glory because it was his achievement.'*



Frost repaired his machine after hitting the tree, but in the autumn of 1896 it was ripped from its moorings and damaged by gales. According to T.G. Sticking's *The Story of Saundersfoot*, Frost's machine was a triplane, and in a raging storm it lifted off and landed two miles (3.2 km) away, in pieces. Frost then travelled to London to solicit funding from the government's war department, but he was turned down. He received several approaches from foreign governments for the rights to his patent, but refused on the grounds of patriotism. On BBC Radio 4's *Flying Starts* programme of 1 August 1998 the presenter noted that '*The Wright brothers had the benefit of independent witnesses, log books full of technical data and, most important, photographic evidence, yet there are compelling reasons for thinking that the first person to fly was Bill Frost.*' In an interview given in 1932, three years before his death, Frost described himself as 'the pioneer of air travel'. Then aged 85 and blind, he spoke of his lack of funding after the war department dismissed his efforts, arguing that '*the nation does not intend to adopt aerial navigation as a means of warfare*'. *The Sunday Times* article continues: '*His determination to fly his aircraft after the initial flight was defeated by bad luck and lack of money.*' Frost's flying machine predated the Wright brothers' Flyer I by seven years.

THE WRIGHT FLIGHTS

THE FIRST flight of the aircraft named Wright Flyer I on 17 December 1903 by Orville Wright (1871–1948) lasted just 12 seconds and covered a distance of 120 feet (*36.5* m) at a speed of 6.8 miles per hour (11 kph). The next two flights on that day covered approximately 175 feet (53 m) and 200

feet (61 m) and were piloted by by Wilbur Wright (1867–1912) and Orville Wright respectively. Their altitude was about 10 feet (3 m) above the ground. Orville Wright said of the fourth and final flight of the day: '*Wilbur started the fourth and last flight at just about 12 o'clock. The first few hundred feet were up and down, as before, but by the time three hundred ft had been covered, the machine was under much better control. The course for the next four or five hundred feet had but little undulation. However, when out about eight hundred feet the machine began pitching again, and, in one of its darts downward, struck the ground. The distance over the ground was measured to be 852 feet; the time of the flight was 59 seconds. The frame supporting the front rudder was badly broken, but the main part of the machine was not injured at all. We estimated that the machine could be put in condition for flight again in about a day or two.*' Fred C. Kelly, *The Wright Brothers: A Biography Authorized by Orville Wright*, 1943

RADIO

—— 1896 ——

NIKOLA TESLA 1856–1943, AUSTRIAN EMPIRE (MODERN CROATIA) AND UNITED STATES

The invention of radio revolutionized communications across the world. Radio owes its development to the inventions of the telegraph and telephone, and radio technology was originally called *wireless telegraphy*. The technology was born with the discovery of *radio waves*, electromagnetic waves that have the capacity to transmit music, speech, pictures and other data through the air. Many devices now work by using electromagnetic waves including radio, microwave cookers, cordless phones, remote controlled toys, television broadcasts and many more. Nikola Tesla patented the basic system of radio in 1896, and his schematic diagrams described all the basic elements of the radio transmitter which was later used by Guglielmo Marconi (1874–1937). In 1896 Tesla constructed an instrument to receive radio waves, transmitting from his laboratory on South 5th Avenue, New York to his room at the Gerlach Hotel in Manhattan. (It is now renamed the Radio Wave building.) The device had a magnet which gave off intense magnetic fields of up to 20,000 lines per centimetre. Five years later, in December 1901, Marconi established

wireless communication between Britain and Newfoundland, Canada, earning him the Nobel Prize in Physics in 1909. However, much of Marconi's work was not original. In 1864 James Maxwell had theorized about electromagnetic waves, and in 1887 Heinrich Hertz proved Maxwell's theories. Later, Sir Oliver Lodge extended the Hertz prototype system. The Branly coherer (an early type of radio signal detector) increased the distance messages could be transmitted, and Marconi's contribution to radio development was mainly in perfecting Branly's coherer. The coherer was a key enabling technology for radio, but was then replaced in receivers and rendered obsolete by the simpler and more sensitive crystal detector around 1907.

SEEING INTO THE FUTURE

'*AS SOON as it is completed, it will be possible for a business man in New York to dictate instructions, and have them instantly appear in type at his office in London or elsewhere. He will be able to call up, from his desk, and talk to any telephone subscriber on the globe, without any change whatever in the existing equipment. An inexpensive instrument, not bigger than a watch, will enable its bearer to hear anywhere, on sea or land, music or song, the speech of a political leader, the address of an eminent man of science, or the sermon of an eloquent clergyman, delivered in some other place, however distant. In the same manner any picture, character, drawing, or print can be transferred from one to another place. Millions of such instruments can be operated from but one plant of this kind. More important than all of this, however, will be the transmission of power, without wires, which will be shown on a scale large enough to carry conviction.*' Nikola Tesla 'The Future of the Wireless Art' in *Wireless Telegraphy and Telephony*, 1908

However, the heart of radio transmission is based upon four tuned circuits for transmitting and receiving. This is Tesla's original concept, demonstrated in his famous lecture on wireless energy transfer at the Franklin Institute in Philadelphia in 1893. The four circuits, used in two pairs, are still a fundamental part of all radio and television equipment. In 1897, at the age of 41, Tesla filed the first radio patent, and a year later demonstrated a radio-controlled boat to the US Navy and the public. In 1904 the US Patent Office reversed its decision and awarded Marconi the patent for radio, and Tesla began his fight to re-acquire the radio patent. A few months after his death in 1943, the US Supreme Court upheld Tesla's patent, in a ruling that served as the basis for patented radio technology in the United States. It finally recognized Tesla's more significant contribution as the inventor of radio technology.

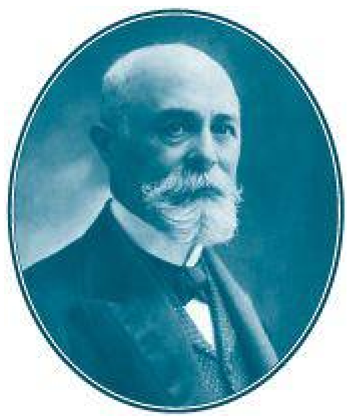
RADIOACTIVITY

—— 1896 ——

ANTOINE HENRI BECQUEREL 1852–1908, FRANCE

A French physicist, Becquerel's earliest work was concerned with the plane polarization of light, the phenomenon of phosphorescence and the absorption of light by crystals. In 1896 this work was overshadowed by his discovery of the phenomenon of natural radioactivity. He had discussed with Henri Poincaré the radiation which had recently been discovered by

Röntgen (X-rays), which was accompanied by a type of phosphorescence in the vacuum tube. Becquerel then decided to investigate whether there was any connection between X-rays and naturally occurring phosphorescence. Becquerel's working hypothesis was that a body had to luminesce to emit penetrating radiation such as Röntgen had found. He had inherited from his physicist father a supply of uranium salts, which phosphoresce on exposure to light. When these salts were placed near a photographic plate covered with opaque paper, the plate was discovered to be fogged. The phenomenon was found to be common to all the uranium salts studied and it was concluded to be a property of the uranium atom. His discovery led Becquerel to investigate the spontaneous emission of nuclear radiation. The uranium, it seemed to him, was making X-rays by itself, but this was not entirely correct, as the lump of potassium uranyl sulphate was emitting a whole spectrum of radiation, not just specifically X-rays.



Later, Becquerel showed that the rays emitted by uranium caused gases to ionize, and that the rays differed from X-rays because they could be deflected by electric or magnetic fields. Scientists across the world took up Becquerel's work. Radioactivity was something entirely new, something that did not fit anywhere in the physics of the day. The existence of a radioactive metal emitting energy was an attack on the Law of Conservation of Energy, whereby energy was neither created nor destroyed. However, every single piece of uranium seemed to be able to produce radiation that fogged photographic plates, ionized gases and sometimes even burned the physicists conducting the experiments. In 1903, he shared the Nobel Prize in Physics with Pierre and Marie Curie '*in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity*'.

The Curies received it for their '*their joint researches on the radiation phenomena discovered by Professor Henri Becquerel*'. Becquerel's work had been the breakthrough event in atomic theory. The SI unit for radioactivity, the becquerel (Bq) is named after him, as are craters on both the Moon and Mars.

ELECTRON

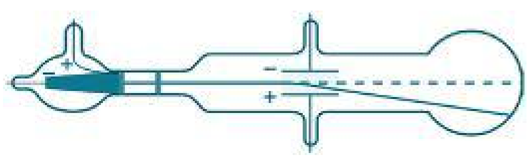
—— 1897 ——

JOSEPH JOHN (J.J.) THOMSON 1856–1940, MANCHESTER, ENGLAND

J.J. Thomson was the first person to prove that the atom consisted of smaller particles. He was a mathematical physicist at Trinity College, Cambridge, working on mathematical models to try and reveal the nature of atoms and electromagnetic forces. In 1884 he was awarded the prestigious Cavendish Professorship of Experimental Physics at Cambridge. Thomson discovered the *electron* in a series of experiments designed to study the nature of electric discharge in a high-vacuum cathode-ray tube. He was thus the first to prove that atoms had constituent 'parts'. He advanced the idea that cathode rays are really streams of very small pieces of atoms. All previous attempts had failed when physicists had tried to bend cathode rays with an electric field. This is because a charged particle will normally curve as it moves through an electric field, but not if it is surrounded by a conductor such as a sheath of copper. Thomson suspected that the traces of gas remaining in the tube were being turned into an electrical conductor by the cathode rays themselves. To test his hypothesis, he managed to extract nearly all of the gas from a tube, and found that now the cathode rays did bend in an electric field after all. He concluded '*I can see no escape from the conclusion that* [cathode rays] *are charges of negative electricity carried by particles of matter.*' Thomson interpreted this detectable deflection of the rays by electrically charged plates and magnets as evidence of '*bodies much smaller than atoms*'.

Later Thomson estimated the value of the 'charge-to-mass ratio' itself. In 1904 he suggested a model of the atom as a sphere of positive matter in which electrons are positioned by electrostatic forces. His efforts to estimate the number of electrons in an atom initiated the research which his student, the great Ernest Rutherford, pursued. Thomson's last important

experimental programme focused on determining the nature of positively charged particles, and his new techniques led to the development of the mass spectrograph. Thomson received the Nobel Prize in Physics in 1906 for his researches into the discharge of electricity in gases, and no less than seven of his research students and close associates later received their own Nobel prizes, including Rutherford (chemistry, 1908) and Francis Aston (chemistry, 1922). Thomson's major hypotheses were that cathode rays are charged particles (which he called *corpuscles*), and that these corpuscles were constituents of the atom. This was met with great scepticism, as the atom was considered indivisible. Under some conditions electrons act like particles; under other conditions they act like waves. The wave character of electrons was in fact experimentally indicated by J.J. Thomson's own son, G.P. Thomson, who as a result shared the Nobel Prize in 1937. Physicists have since found that electrons are only the most common members of a whole family of related fundamental particles. All of them are infinitesimally small points carrying charge, mass and something called *spin*. The reason for the properties of these sub-atomic particles has become the last frontier for research.



THOMSON'S MASS SPECTROGRAPH AND CSI

THE MASS spectrograph is used in laboratories to identify the chemical constituents of any sample provided, whether it comes from a crime scene investigation (CSI), a toxic substance found in a river or an unknown chemical in a compound. In order to identify a substance, which may contain many different elements, it is first necessary to burn a small quantity of the material, and apply a charge to the particles. This gas composed of ions is collected in a container, and the ions then need to be identified. Atoms have been given a charge (making them ions), so that they can be attracted by a magnet. (If you shoot a beam of ions past a magnet, it will pull on all of them, and the less massive the ions are, the more the beam of ions will be deflected.) Thus it is possible to calculate the mass of

an ion by measuring how much it deflects when passed through a magnetic field of known strength.

ASPIRIN

—— 1897–1900 ——

CHARLES FRÉDÉRIC GERHARDT 1816–1856, FRANCE, AND FELIX HOFFMANN 1868–1946, GERMANY

Aspirin, or acetylsalicylic acid, is a derivative of salicylic acid. The tablet was the precursor of modern mass-produced medicines, and has probably cured more minor ills than any other drug. It is a mild, non-narcotic analgesic used in the relief of headaches and muscle and joint aches. It works by inhibiting the production of prostaglandins, body chemicals which are necessary for blood clotting and which also sensitize nerve endings to pain. Hippocrates (*c*.460–370 BCE) first wrote of the healing power of the tea made from willow bark and leaves, finding it effective against fevers, headaches, pains and gout. The Reverend Edward Stone (1702–1768) later discovered salicylic acid, the active ingredient of aspirin, when he noted in 1763 that willow bark was effective in reducing a fever. He experimented by gathering and drying a quantity of willow bark and creating a powder which he gave to about 50 people. It was consistently found to be a '*powerful astringent and very efficacious in curing agues and intermitting disorders*'. This active ingredient in willow bark was first isolated in pure form in 1828 by Johann Buchner, professor of pharmacy at the University of Munich. He called it *salicin* (*Salix* is the botanical genus name of willow trees). By 1829 the French chemist Henri Leroux had improved the extraction procedure so as to obtain about 1 ounce (30 g) of it from 3 pounds 5 ounces (1.5 kg) of bark. In 1838 the Italian chemist Raffaele Piria split salicin into a sugar and an aromatic component (salicylaldehyde) and converted the latter to an acid of crystallized colourless needles, which he named *salicylic acid*. A major problem was that 'neat' salicylic acid caused stomach upsets, so a means of *buffering* the compound was needed. In 1853 the French chemist Charles Frédéric Gerhardt neutralized salicylic acid by buffering it with sodium (sodium salicylate) and acetyl chloride, creating acetylsalicylic acid. Gerhardt's product worked effectively, but he had no desire to market it and abandoned his discovery.

GERMAN REPARATIONS

IN THE United States Bayer was able to obtain a patent in 1900, giving the company the monopoly on manufacturing the drug Aspirin. When Bayer’s American plants were sold in 1919 as part of the reparations exacted from Germany after the First World War, Sterling Products invested $3 million to buy them. However, Sterling was unable to protect the trademark status of ‘Aspirin’ and it became a generic staple medicine of the over-the-counter drug market across the world. Today, over 70 million pounds (32 million kg) of aspirin are produced annually around the world, and Americans alone consume more than 15 billion tablets per year.

In 1894 the German chemist Felix Hoffmann joined the pharmaceutical research facility of the Bayer Company, where he produced a stable form of acetylsalicylic acid in 1897. He had studied Charles Gerhardt’s experiments and ‘rediscovered’ the pain-relieving, fever-lowering and anti-inflammatory acetylsalicylic acid. After extensive testing, in 1899 it was launched to physicians under the trade name *Aspirin*, initially as a powder supplied in glass bottles. From 1899 acetylsalicylic acid attained a leading position worldwide in the prescription-free treatment of painful, inflammatory and feverish states. In 1900 Bayer introduced Aspirin in water-soluble tablets, the first medication to be sold in this form. 1915 saw Aspirin becoming available without a prescription, and being manufactured in tablet form. Dr Lawrence Craven in 1948 noticed that aspirin reduced the risk of a heart attack, and in 1971 pharmacologist John Vane recognized that aspirin

worked by inhibiting the generation of prostaglandins. People at risk of heart attack are advised to take an aspirin a day, and aspirin is used to prevent and treat stroke. Aspirin is also thought to be a potent drug for treatment of cancer, heart disease, Alzheimer's disease, stroke, infertility, herpes and blindness. Studies have shown that long-term aspirin taking can reduce the risk of death from colon cancer by over 40 per cent. Like Gerhardt before him, Hoffmann never gained the international recognition he deserved for his discovery.

RADIUM

—— 1898 ——

PIERRE CURIE 1859–1906, FRANCE, AND MARIE CURIE (NÉE SKLODOWSKA) 1867–1934, POLAND AND FRANCE

Radium radioactivity enabled enormous advances in medicine and physics. The Polish scientist Marie Curie was the first woman to win a Nobel prize. She was also the first woman in France to earn a PhD where she had married Pierre Curie, who taught physics at the University of Paris. They found that uranium ore (pitchblende) emitted much more radioactivity than could be explained solely by its uranium content. She had hypothesized that the emission of rays from uranium could be an atomic property of the element, something built into the structure of its atoms. This was revolutionary, as scientists still regarded the atom as the fundamental, indivisible particle. No-one understood the complex inner structure of, or the immense energy stored in, atoms, and only now was the electron being discovered. In April 1898 her research revealed that thorium compounds, like those of uranium, emitted 'Becquerel rays'. Again the emission appeared to be an atomic property. To describe the behaviour of uranium and thorium she invented the word *radioactivity*, based on the Latin word for ray.

The Curies then searched for the source of the radioactivity and discovered two highly radioactive elements, radium and polonium, jointly winning the 1903 Nobel Prize in Physics with Becquerel. The chemical element she named radium is over one million times more radioactive than the same mass of uranium. It is luminous because of its instability. She named polonium after her native country, then still partitioned between

Russia, Prussia and Austria. In 1906 Pierre died, but Marie Curie continued her researches. In 1911 she won the Nobel Prize in Chemistry for isolating radium, but never managed to isolate polonium, as *half-life* radioactive decay was not understood at that time. Radium's tremendous radioactivity seemed to contradict the principle of the conservation of energy, forcing a reconsideration of the foundations of physics. Radium also provided Ernest Rutherford and others with sources of radioactivity with which they could probe the structure of the atom. As a result of his experiments, the nuclear atom was first hypothesized. In medicine, the radioactivity of radium appeared to offer a means by which cancer could be successfully attacked. When the First World War broke out, Madame Curie thought X-rays would help to locate bullets in wounds and so facilitate surgery. It was important not to move the wounded, so she invented X-ray vans and trained 150 female attendants. Madame Curie died of aplastic anaemia, brought on by exposure to the high levels of radiation involved in her research. As a footnote, polonium was used in 2006 by an assassin, allegedly working for the Russian security services, to murder the Russian dissident Alexander Litvinenko in London.

PURE SCIENTIFIC RESEARCH

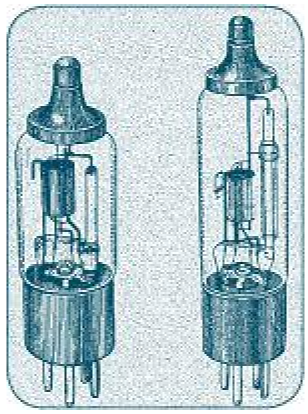
'*WE MUST not forget that when radium was discovered no one knew that it would prove useful in hospitals. The work was one of pure science. And this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it. It must be done for itself, for the beauty of science, and then there is always the chance that a scientific discovery may become like the radium a benefit for humanity.*' Marie Curie, during a lecture given at Vassar College, Poughkeepsie, New York, 14 May 1921

THERMIONIC VALVE (VACUUM TUBE)

—— 1904 ——

JOHN AMBROSE FLEMING 1849–1945, ENGLAND

Fleming's invention of the thermionic valve (vacuum tube) could be said to mark the beginning of modern electronics. Professor of physics and mathematics at Nottingham University, Fleming took up a position as a consultant to the Edison Telephone Company. This enabled him to see many of Edison's inventions, and he even travelled to visit Edison's laboratories in the United States. Here Fleming saw a discovery known as the *Edison effect*. It was found that in an evacuated light bulb containing a second electrode, current would flow from one electrode to the other, but only in one direction. Fleming became professor of electrical engineering at University College, London. In 1899 Fleming was appointed a consultant to the Marconi Company in addition to his duties at UCL. At this time *wireless*, as radio was then known, was still in its infancy and Marconi was continually striving to extend the distance over which a signal could be transmitted. Fleming designed the transmitter that made the first transatlantic transmission. Fleming recognized that the major problem that prevented vast improvements being made was that of detecting the signals. The coherer was initially the main form of detector and it was very insensitive, so Fleming researched a replacement device. In November 1904 Fleming applied for a patent on the two-electrode vacuum-tube rectifier, which he called the *oscillation valve*. Shortly after his discovery Fleming wrote to Marconi to tell him of his discovery, saying that he had not mentioned the idea to anyone else as he thought it might be very useful.



The invention was also called a *thermionic valve*, from the Greek *thermos*, meaning warm. Fleming called it a valve because it allowed electrical currents to pass in one direction only. It was also called a rectifying vacuum tube. In it, the electrons flow from the negatively charged cathode to the positively charged anode. As the current within the tube is moving from negative to positive, the oscillations of incoming signal are *rectified* into detectable direct current. Fleming made many adjustments to his valve over the next few years. They included tungsten filaments and the addition of a shield within the tube to eliminate electrically charged bodies from affecting the valve. Fleming applied for a patent for his improved diode vacuum tube in 1908. The valve was used in several electrical devices soon after its development, such as the Marconi-Fleming Valve Receiver. This was the start of the wireless revolution. Fleming's invention led to one of the most famous litigations in scientific history, Fleming vs. De Forest. Dr Lee De Forest had made a significant contribution by introducing a grid between the filament and the plate in Fleming's valve, which allowed control of the current flow. The legal action centred over whether the addition of the grid to the valve – i.e. the addition of the third electrode – was an invention in its own right. The Marconi Company asserted that it was not, whereas De Forest took the opposite view, contending that what Fleming claimed as invention was already inherent in Edison's patent of 1883. After a massively costly process in the courts, it was not until 1920 that a settlement was found, in favour of John Fleming.

THEORIES OF RELATIVITY

— 1905 —

ALBERT EINSTEIN 1879–1955, SWITZERLAND AND UNITED STATES

Einstein was the most important scientist since Sir Isaac Newton with regard to his contribution to the understanding of physical reality. Einstein graduated as a physics and mathematics teacher in Zurich in 1901, but could not find employment, so worked as a technical assistant in the Swiss Patent Office from 1902–9. Here, in his spare time, he worked tirelessly in writing papers on theoretical physics, away from the influence of academia or scientific colleagues. In 1905, aged just 26, he published four major papers each of which was an astounding breakthrough. His '*special theory of relativity*' reconciled mechanics with electromagnetism. Secondly, his '*general theory of relativity*' created a new theory of gravitation, based on the principle that the laws of physics (such as the speed of light) are in the same form in any frame of reference. This established that Newton and Galileo were wrong about the way the Universe worked. Einstein explained for the first time how space and time work. Special relativity shows that measurements of distance and time depend on how fast you are travelling. The most famous part of special relativity is the famous equation: $E = mc^2$ (energy equals mass times the velocity of light squared), which became a building-block in the development of nuclear energy. His special and general theories of relativity are still regarded as the most satisfactory model of the large-scale Universe that we have.

Thirdly, Einstein proved the existence of atoms by calculating the movements of particles suspended in a fluid, such as pollen grains jiggling around in water – so-called *Brownian motion*. The invisible atoms in the water bounce around the pollen grains kicking them like footballers kick a ball. The discovery paved the way for other scientists to identify methods for measuring the size of atoms, on the basis of how fast they move.

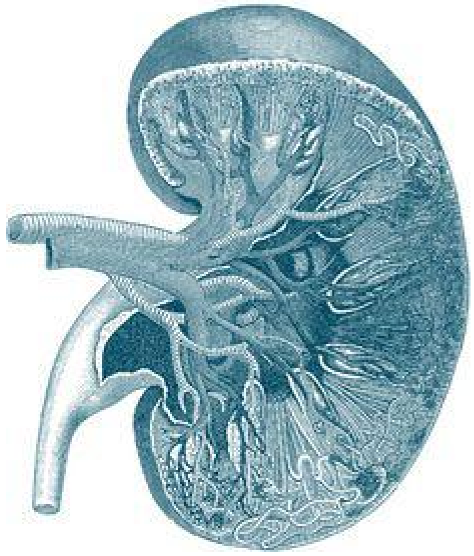
However, Einstein received the Nobel Prize in 1921 for his 1905 work on the photoelectric effect, rather than his contributions to relativity or atomic theory. The photoelectric effect reversed the thinking that light came in ‘waves’, identifying instead that it is made up of *packages* of energy or *photons*. This explained anomalies in the energy contained in different colours of light which had puzzled Einstein’s predecessors. His discovery paved the way for other scientists to develop the fields of quantum physics and quantum mechanics. In 1999 *Time* magazine named Einstein *Person of the Century*.

ORGAN AND TISSUE TRANSPLANTATION

—— 1905 ——

EDUARD KONRAD ZIRM 1863–1944, AUSTRIA AND MORAVIA

Organ and tissue transplants have given hope to hundreds of thousands of people who would otherwise die from their illnesses. The techniques of organ and tissue transplantation are improving rapidly, particularly with the use of new immunosuppressant drugs. There is also an emerging field of *regenerative medicine* allowing organs to be re-grown from the patient’s own stem cells, or cells extracted from the failing organs. Organs and/or tissues that are transplanted within the same person’s body are called *autografts*. Transplants that are performed between two separate individuals are called *allografts*, and can come from either a living or a dead source. Organs that have been successfully transplanted are the heart, kidneys, liver, lungs, pancreas, intestine, thymus and eyes. Transplanted tissues include bones, tendons (both called ‘musculoskeletal grafts’), cornea, skin, heart valves and veins. Kidneys are the most commonly transplanted organs, followed closely by the liver and then the heart. The cornea and musculoskeletal grafts are the most commonly transplanted tissues, outnumbering organ transplants more than tenfold. Organs generally need to be transplanted within 24 hours of donation or death. However, most tissues (with the exception of corneas) can be preserved and stored for up to five years, meaning that they can be placed in a ‘tissue bank’.



The first reasonable account of transplantation is that of the Indian surgeon Sushruta around 550 BCE or earlier, who used autografted skin in nose reconstruction. The Italian surgeon Gasparo Tagliacozzi (1546–1599) also performed successful skin autografts, but failed consistently with allografts, not understanding the mechanism of *tissue rejection*. The first successful human corneal transplant was performed by the Viennese doctor Eduard Zirm in Moravia, which is now in the Czech Republic. This was the first successful tissue allograft, and his method remains the basis for repairing corneal damage. In the early 1900s the transplantation of arteries and veins was pioneered, with new suturing techniques. Transplant success rates suffered because of donor organ rejection by the host, but the 1970 discovery of the immunosuppressant drug *cyclosporine* proved a huge advance. South African surgeon Christiaan Barnard carried out the first heart transplant in 1967, with the patient surviving for 18 days. More than 100 such operations were performed in 1968–9, but almost all the patients died within 60 days. However, Barnard’s second patient lived for 19 months. It was the advent of cyclosporine that changed the status of transplants from research surgery to life-saving treatment. By 1984 two-thirds of all heart transplant patients survived for five years or more. With organ transplants becoming commonplace, limited only by the availability of donors, surgeons moved into fields such as multiple-organ transplants on humans.

TRANSPLANT PROGRESS

A LIST of the first successful transplants includes:

cornea 1905 (Czech Republic)
kidney 1954 (USA)
pancreas 1966 (USA)
liver 1967 (USA)
heart 1967 (South Africa)
heart/lung 1968 (USA)
lung 1983 (Canada)
double lung 1986 (Canada)
hand 1998 (France)
tissue-engineered bladder 1999 (USA)
partial face 2005 (France)
jaw 2006 (USA)
double arm 2008 (Germany)
windpipe using patient's own stem cells 2008 (Spain)
full face 2010 (Spain)

TRIODE AMPLIFIER ('AUDION TUBE') AND AM RADIO

—— 1907 ——

LEE DE FOREST 1873–1961, UNITED STATES

While studying at Yale University, De Forest helped to pay for his tuition with income derived from his mechanical inventions. In the early 1900s what was most needed to develop radio technology was a more efficient and sensitive detector of electromagnetic radiation. In his research De Forest began to conceive of an improvement to Fleming's *diode* vacuum tubes that were used at the time. They could 'rectify' signals (from AC to DC), but not amplify them. They were also not subtle enough to respond to changes in incident electromagnetic radiation. In 1906 De Forest found a simple but ingenious solution to these problems: he added a third electrode between the other two in the diode. De Forest's patented *triode* or *Audion* tube could both rectify and amplify, and its greater control it meant that various electronic circuits would finally be commercially feasible. De Forest had made it possible to amplify the radio frequency signal picked up by the antenna, before application to the receiver detector, and using much weaker signals. Until this time the radio was considered little more than *wireless*

telegraphy since it was normally used to send Morse code, instead of conveying actual sound. De Forest's new vacuum tube boosted radio waves and made possible what was then called *wireless telephony*. This *amplitude modulation* (A.M.) enabled a multitude of radio stations to broadcast across America. It became the preferred radio technology until the relatively recent development of frequency modulation (F.M.). De Forest was also the first person to use the word *radio*, not liking the term *wireless*. 'The father of radio' made radio broadcasting practicable. As he observed in his *Autobiography* (1950): '*Unwittingly then had I discovered an Invisible Empire of the Air, intangible, yet solid as granite, whose structure shall persist while man inhabits the planet.*'

De Forest founded a company in 1907 to make commercial broadcasting a reality. He is credited with the birth of public radio broadcasting on 12 January 1910 with the transmission of *Tosca* from the Metropolitan Opera House in New York. However, the US District Attorney sued De Forest in 1913 for defrauding his shareholders with what it called '*absurd*' promises for his Audion tube. De Forest persevered, and in 1916 notched up two triumphs: the first radio advertisement (for his own products) and the first American presidential election reported by radio. His Audion tube became an essential component of not only commercial radio, but also the telephone, television, radar and computer. Although solid-state transistors replaced the bulky Audion tubes originally used in these devices, De Forest's inventions and enthusiasm paved the way for the electronic age.

AGE OF PLASTICS

—— 1907 ——

LEO HENDRIK BAEKELAND 1863–1944, BELGIUM

In 1893 this Belgian chemist invented *Velox* photographic paper, which allowing reasonable pictures to be taken in artificial light. In 1899 George Eastman paid Baekeland $1,000,000 for the Velox process, and with the proceeds he set up a chemical company in New York. In his new laboratory, Baekeland controlled the pressure and temperature applied to phenol (carbolic acid) and formaldehyde, producing a substance called polyoxybenzylmethylenglycolanhydride. He called this hard, but mouldable and extrudable plastic *Bakelite*, announcing it to the world in 1912. It was

inexpensive, non-flammable and versatile. Bakelite was the first plastic invented that held its shape after being heated, and soon radios, telephones, clocks and electrical insulators were taking advantage of its insulation and heat-resistant properties. It was even made into billiard balls. It was the first true plastic to be invented. Bakelite was a purely synthetic material, not based on any material or even any molecule found in nature. It was also the first thermosetting plastic. Conventional thermoplastics can be moulded and then melted again, but thermoset plastics form bonds between polymer strands when cured, creating a tangled matrix that cannot be undone without destroying the plastic. Thermoset plastics are tough and temperature-resistant.

To a great extent advances in plastics are now led by the other type of plastic, thermoplastics which can be heated and moulded again and again, such as PVC, PTFE, polyethylene and polypropylene. The raw materials to make plastics generally come from petroleum and natural gas. After the First World War, research and innovation in plastics accelerated with the invention of PVC and polystyrene, followed by polyamide (the first purely synthetic fibre we know as *nylon*) in the 1930s. Due to their relatively low cost, ease of manufacture, versatility and imperviousness to water, plastics are used in an enormous and expanding range of products, displacing many traditional materials, and modern life would be unrecognizable without plastic technology. We daily use polyesters for film, textiles and clothing; polyethylene for food containers, packaging, outdoor furniture; PVC for drainpipes and window frames; polypropylene for yogurt containers and car bumpers; polystyrene for packaging foam and plastic cups; polyamides for mouldings and toothbrush bristles; ABS for computer monitors and keyboards; polycarbonate for compact discs and lenses; polyurethane in thermal insulation and paints; melamine in children’s cups and with Formica work surfaces; polymethyl in contact lenses and as Perspex

glazing; PTFE for nonstick surfaces in cooking; and ureaformaldehyde as a wood adhesive.

MULTI-ENGINED FIXED-WING AIRCRAFT AND AIRLINER

—— 1913 ——

IGOR IVANOVICH SIKORSKY 1889–1972, RUSSIA AND UNITED STATES

Sikorsky revolutionized air transport more than any other man. After engineering training in Paris, Sikorsky returned to Russia in 1909 and began to design helicopters, but he soon realized the technological limitations of the time. He began to build fixed-wing aircraft, and his fifth model was the the two-seat *S-5*, the first design not based on other European aircraft. During a flight, he was forced to crash-land. He discovered that a mosquito in the gasoline had been drawn into the carburettor, starving the engine of fuel. He determined to build a multi-engine plane to stop the problem occurring again. He next designed the *S-6* plane which held three passengers and was praised by the Russian Army in 1912. Sikorsky in 1913 designed and flew the world's first multi-engine fixed-wing aircraft, the four-engined *S-21 Russky Vityaz* (Russian Knight), which he test flew in St Petersburg. Experts and media around the world scoffed at his proposals, but the aircraft flew successfully.

Sikorsky took his experience from building the *Russky Vityaz* to develop the *S-22 Ilya Muromets*, the world's first airliner in 1913. Its revolutionary design was intended for commercial service with spacious fuselage incorporating for the first time an insulated passenger saloon, comfortable wicker chairs, a bedroom, a lounge and even the first airborne toilet. The aircraft also had heating and electric lighting. The cockpit had sufficient space to allow several persons to observe the pilot. Openings on both sides of the fuselage permitted mechanics to climb out onto the wings to service the engines during flight. An exterior catwalk on top of the fuselage allowed passengers to experience the flight al fresco. The first flight was in December 1913, and in February 1914 it took off for its first demonstration flight with 16 passengers aboard. This marked a record for number of passengers carried in a plane. From 30 June to 12 July 1914, it set a world record by making a trip from St Petersburg to Kiev, a distance of some 750 miles (1200 km), and back. The first leg took 14 hours and 38 minutes with

one landing for fuel, and the return trip, again with one fuel stop, took 13 hours. When the First World War broke out, Sikorsky redesigned the *Ilya Muromets* as the world's first four-engined bomber. This heavy warplane was unrivalled in the early stages of the war, as the Central Powers had no aircraft capable enough to challenge it until much later.

After the war, the Russian Revolution caused turmoil in his native country so Sikorsky eventually emigrated to the USA, where he founded the Sikorsky Aircraft Corporation in 1923. The company was financially insecure when it built his *S-29-A* (*America*), and this twin-engined, all metal aircraft was the forerunner of all modern airliners. An amphibian version, the *S-38*, was a massive success, and was used by Pan American Airways to open new air routes across the world. (The 38 number signified that it was the 38th aircraft that Sikorsky had designed). Later, as a subsidiary of United Aircraft Corporation (now United Technologies), Sikorsky's company manufactured the *Flying Clippers* which pioneered commercial air transport across both the Atlantic and Pacific Oceans. The last Sikorsky flying boat, the *S-44*, held the Blue Ribbon for the fastest trans-Atlantic passage for many years. However, by now Sikorsky was spending nearly all of his time developing helicopter technology.

MOVING ASSEMBLY LINE AND MASS PRODUCTION

—— 1914 ——

HENRY FORD 1863–1947, UNITED STATES

Ford's moving assembly lines were copied in all manufacturing industries, and his Model T motor car heralded the beginning of the *Motor Age*. Ford said that he had to invent his *gasoline buggy* to escape the boredom of life on a farm. By 1896 he had constructed his first horseless carriage, which he sold to finance work upon an improved model. He incorporated the Ford Motor Company in 1903, stating '*I will build a car for the great multitude*'. In 1908 the Model T was offered for just $950, and was an instant sensation. The car had the steering wheel on the left, instead of in the middle, an arrangement which every other company soon copied. The entire engine and transmission were enclosed, the engine's four cylinders were cast in a solid block and the suspension used two semi-elliptic springs. The car was simple to drive, rugged and easy and cheap to repair. It became even cheaper at $825 in 1908, and the price fell every subsequent year, owing to decreasing production costs. After installing moving assembly lines in its factories in 1913, Ford became the world's biggest car manufacturer. By 1916, as the price dropped to $360 for the basic touring car, sales reached 472,000 per annum, and in its 19 years of production, the price dropped as low as $280. By the 1920s, most American drivers had learned to drive on the Model T. By 1927 over 15 million Model Ts had been manufactured, and it remained the world's most popular car until overtaken by the Volkswagen Beetle. With the Model T, the car evolved from a luxury item for the rich to essential transportation for the ordinary man. The car transformed American society in other ways. As more Americans owned cars, so urbanization patterns changed. There was the growth of suburbs as people could travel greater distances to work, the creation of a national highway system and more efficient distribution systems that were no longer dependent on the railways and horse transportation.

Ford revolutionized manufacturing. The production time for his early cars was 728 minutes but the installation of the first conveyor belt-based assembly line in his Michigan plant, around 1913–14, using innovative production techniques, changed all this. It could turn out a complete chassis every 93 minutes. Using a constantly moving assembly line, subdivision of labour, and careful coordination of operations, the company made huge gains in productivity. In 1914 Ford began paying his employees $5 a day, nearly doubling the wages offered by other manufacturers. One of the reasons was to enable them to buy his cars. He cut the workday from nine to eight hours, not for philanthropic purposes, but to convert the factory to a three-shift, 24-hour workday. In 1932 Henry Ford introduced his last engineering triumph, the superb one-piece V-8 engine. In its final years of production, a Model T could be produced in 34 minutes, and all spare parts were available through the Sears Roebuck mail-order catalogue. An interesting aspect of Ford's influence on motor transport is reflected by his litigation with George B. Selden. Selden, who had never built a car, held a patent on a *road engine*, and on that basis Selden was paid royalties by all American car manufacturers. Ford overturned Selden's patent and thus opened the American car market for the building of inexpensive cars.

BLACK IS THE NEW BLACK

FORD WAS obsessed with efficiency, and his production lines were inspired by the meat-packing yards of Chicago. By 1918 half of all cars in America were Model T's. However, nearly all of them were painted monotonous black. As Ford wrote in his autobiography, '*Any customer can*

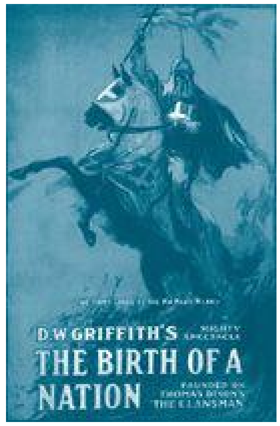
have a car painted any colour that he wants so long as it is black.' Until his adoption of the production line in 1914, his cars were available in several other colours. His decision to standardize on black was not taken to limit consumer choice, but to reduce costs. In Ford's time freshly painted cars were left in the sun to dry, not placed in ovens as today. Black dried more quickly, and it was thus quicker and cheaper to produce black cars with the moving assembly lines. Black paint was also cheaper to buy and more durable. During the lifetime production of the Model T, over 30 different types of black paint were used upon various parts of the car, and they were formulated to satisfy the different means of applying the paint to the various parts. Each had distinct drying times, depending on the part, paint, and method of drying.

CINEMA TECHNIQUES

—— 1914 ——

DAVID LLEWELYN WARK (D.W.) GRIFFITH 1875–1948, UNITED STATES

Griffith made hundreds of short films before his masterpieces *The Birth of a Nation* (1915) and *Intolerance* (1916). Other major films made between 1918 and 1922 were *Hearts of the World*, *Broken Blossoms* and *Orphans of the Storm. Hearts of the World* broke new ground by showing war scenes actually filmed at the front during the First World War. Griffith revolutionized cinema techniques, altering film-making forever. He innovated the fade-in, fade-out (*dissolve*), close-up and flashback. He elevated moving pictures from a technological invention to an artistic medium, his epics and masterpieces being seen and copied all over the world. Influenced by European films, Griffith's first full-length movie was *Judith of Bethulia* in 1914. This was a version of the Biblical story of the Book of Judith. His next film *The Birth of a Nation* in 1915 aroused massive controversy. The intimate story of a family torn apart by the American Civil War, it featured epic war scenes, and was the most ambitious film ever made. Strongly pro-South, it engendered riots among some audiences who objected to its benign portrayal of slavery and the Ku Klux Klan.



Griffith now wanted to make a historical blockbuster, and 1916's pacifist *Intolerance* wove together themes of Babylon, Christ's Passion, the St Bartholomew's Day massacre and a story set in contemporary California. The linking motif was man's intolerance to man. He moved away from the linear narrative of *The Birth of a Nation*, pioneering a new type of film-making with the stories being told in a parallel mode, and moving back and forwards in time. It infuriated many Americans, who expected the type of film that Mack Sennett was making with his Keystone Cops – easy-to-follow plot lines featuring clear-cut heroes and villains. The film was critically acclaimed in Europe and Russia, but made losses in America. As a result, the amazingly opulent and sexy Babylonian sequence was re-cut and released as *The Fall of Babylon* to try to generate profits. His vision of peace was not in tune with the mood of a nation preparing to fight in the First World War. Griffith was the major pioneer of today's cinema industry.

MILANKOVIĆ WOBBLES

—— 1914–1918 ——

MILUTIN MILANKOVIĆ 1879-1958, SERBIA

Almost a century ago, MilankoviĆ proved how 'climate change' worked with his '*canon of the Earth's insolation*' and *Ice Age theory*. It had been suggested in 1842 by the French mathematician Joseph Alphonse Adhemar (1797–1862) that astronomical cycles would change the amount of sunlight that reaches the Earth. In *Revolutions of the Sea*, Adhemar wrote that Ice Ages were controlled by astronomical forces during the 26,000 year cycle of the *precession of the equinoxes*. Seventy years later MilankoviĆ, a

Serbian civil engineer and mathematician, was interned during the the First World War in Budapest, and he decided to use his time profitably by researching geophysics.

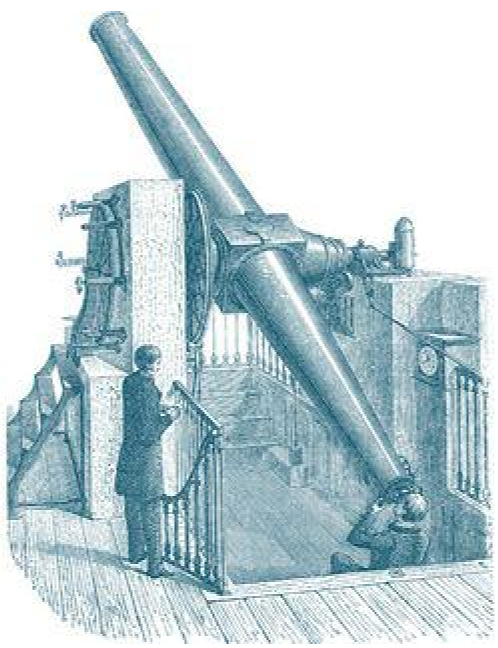
MilankoviĆ dedicated his career to developing a mathematical theory of climate based on the seasonal and latitudinal variations of solar radiation received by the Earth. Now known as the *Milankovitch Theory*, it states that as the Earth travels through space around the Sun, cyclical variations in three elements of Earth–Sun geometry combine to produce variations in the amount of solar energy that reaches Earth. These are the *MilankoviĆ Cycles*, or *MilankoviĆ Wobbles* with which politicians should become acquainted before they spend the West's capital upon inefficient and ineffective renewable technologies. Incidentally, no scientist has ever been able to *renew* energy, only to transform it into another form of energy, thus energy can never be *renewable*, only transformable.

Although the orbital cycles are named after MilankoviĆ, he was not the first to link them to climate. Adhemar (1842) and James Croll (1875) were two of the earliest, but the incredible mathematical work of MilankoviĆ proved the theory. The three periods of orbital motions, or cycles, that he identified are: firstly, variations in the Earth's orbital ***Eccentricity***, the shape of the orbit around the Sun. Currently, a difference of only 3 per cent (3.1 million miles/5 million km) exists between the Earth's closest approach to the Sun (*perihelion*, around 3 January) and the greatest distance from it (*aphelion*, around 4 July). This present difference in distance accounts for about a 6 per cent increase in incoming solar radiation (*insolation*) from January to July. The shape of the Earth's orbit also changes from being elliptical (high eccentricity of around 5 per cent) to being nearly circular (low eccentricity approaching 0 per cent) in a cycle that takes around 100,000 years to complete. When the orbit is highly elliptical, the amount of insolation received at perihelion would be around 20–30 per cent greater than at aphelion, giving a substantially different climate from today.

PIONEER OF CLIMATE CHANGE

MILUTIN MILANKOVIĆ is virtually unknown, but NASA has ranked him as one of the ten greatest scientists of all time, as he developed one of the most significant theories relating Earth planetary motions to long-term climate change. MilankoviĆ followed Joseph Adhemar in postulating the correct

theory of Ice Ages, by showing the relationship between long-term climate and periodic changes in the Earth's orbit. The position of the Earth in relation to the Sun explains not only the climatological past of the Earth, but also predicts the climate changes that can be expected in the future. These extremely slow changes have also been responsible for mass extinctions. His *Canon of the Earth's Insolation* characterizes the climates of all the planets of the Solar System. *Insolation* is the solar radiation that reaches the surface of a planet, measured by the amount of solar energy received per square centimetre per minute. Factors that affect insolation are the angle of the Sun, the distance between the Sun and Earth (or the other planets in the Solar System), the effect of atmosphere and the duration of daylight.



Secondly, changes in ***Obliquity*** are changes in the angle that Earth's axis makes with the plane of Earth's orbit. As the axial tilt increases, the seasonal contrast increases so that winters are colder, and summers are warmer in both hemispheres. The Earth's axis is presently tilted 23.44 degrees and decreasing from the plane of its orbit around the Sun. However, the tilt changes between 22.1 and 24.5 degrees during a cycle that averages about 41,000 years. Because of this change in tilt, the seasons can become exaggerated. A greater tilt means more severe seasons, warmer summers and colder winters, and vice versa. A lesser tilt gives cooler summers which

allow snow and ice to last from year-to-year in high latitudes, eventually building up into massive ice sheets. There are positive feedbacks in the climate system as well, because if Earth is covered with more snow, it reflects more of the Sun's energy into space, causing additional cooling. This is known as the *albedo effect*, as the Sun's energy is reflected back into space from snow, glaciers and sea-ice.

Thirdly, ***Precession*** is the gravity-induced slow and continuous change in the orientation of the Earth's axis of rotation. It is variously known as the *Precession of the Equinoxes*, *Axial Precession* or *Precession of the Equator*. It is the Earth's slow wobble as it spins. The axis of rotation behaves like the spin axis of a top that is winding down, tracing a circle on the celestial sphere over a period of time. Changes in axial precession alter the dates of perihelion and aphelion, and therefore increase the seasonal contrast in one hemisphere and decrease the seasonal contrast in the other hemisphere. The gradual shift in the orientation of our axis of rotation is like a wobbling top, which traces out a pair of cones joined at their apexes in a cycle of approximately 26,000 years. There are also other changes in the alignment of Earth's axis, polar motion and nutation, which have less affect upon climate change.

Using these three orbital variations, MilankoviĆ formulated a comprehensive mathematical model that calculated latitudinal differences in insolation, and the corresponding surface temperature for 600,000 years prior to the year 1800. He then correlated these changes with the growth and retreat of the Ice Ages. He chose summer insolation at 65 degrees North as the most important latitude and season to model, reasoning that great ice sheets grew near this latitude and that cooler summers might reduce summer snowmelt, leading to ice sheet growth. Until 1976, his theory was generally ignored. Then a study published in *Science* examined deep-sea sediment cores and found that his theory corresponded to periods of climate change. The authors extracted the record of temperature change going back 450,000 years and found that major variations in climate were closely associated with changes in the geometry (*eccentricity*, *obliquity*, and *precession*) of Earth's orbit. Ice ages had occurred when the Earth was going through different stages of orbital variation. Indeed, '… *orbital variations remain the most thoroughly examined mechanism of climatic change on time scales of tens of thousands of years and are by far the*

clearest case of a direct effect of changing insolation on the lower atmosphere of Earth.' (National Research Council, 1982).

These variables are vital to understand because the Earth has an asymmetric distribution of landmasses, with most land being located in the northern hemisphere. At times when northern hemisphere summers are coolest (furthest from the Sun due to precession and greatest orbital eccentricity) and winters are warmest (minimum tilt), snow can accumulate on and cover broad areas of northern America and Europe. At present, only precession is in the glacial mode, with tilt and eccentricity not favourable to glaciation. With literally thousands of parameters determining climate change, these three orbital cycles are by a huge factor the most important. Governments have slowly stopped talking about global warming, about which many independent scientists disagree, preferring the more correct term of climate change.

OBSERVATION OF NUCLEAR REACTIONS

—– 1919 —–

ERNEST RUTHERFORD 1871–1937, NEW ZEALAND, ENGLAND AND CANADA

'The father of nuclear physics', Rutherford discovered the proton, proposed a nuclear atomic structure and demonstrated that radioactivity was caused by the spontaneous disintegration of atoms. A New Zealander, Rutherford led physics research in Britain and Canada. He is best remembered for devising in 1898 the names *alpha, beta* and *gamma rays* to classify rays which were poorly understood. Alpha and beta rays are now known to be particle beams, while gamma rays are a form of high-energy electromagnetic radiation. Rutherford deflected alpha rays with both electric and magnetic fields in 1903. He also observed that the intensity of radioactivity fell at a constant rate over time, and named this halving time *half-life* in 1907. By this method Rutherford discovered that the Earth was far older than was thought. In 1906 his students Marsden and Geiger conducted the gold foil alpha particle *Rutherford scattering* experiment, showing large deflections for a small fraction of incident particles. This led Rutherford to propose that the atom was *nuclear* in structure. For his discoveries, Rutherford was awarded the 1908 Nobel Prize in Chemistry. He resented the fact that his prize was in chemistry rather than physics, and

his acceptance speech made a remark to the effect that he had seen many transformations in his studies, but never one more rapid than his own from physicist to chemist. Rutherford had theorized that the simplest possible rays must be those obtained by hydrogen, and that these must be the fundamental positively charged particle, which he named the *proton* in 1914.

In 1919, he passed alpha particles through nitrogen gas and observed random scintillation of hydrogen impacting on his screen. He concluded that alpha particles were knocking protons out of the nitrogen atoms, and thus that he had made the first observation of nuclear reactions. The nitrogen in this process was actually transformed into an oxygen isotope, so that Rutherford was the first to deliberately transmute one element into another. Rutherford had virtually created a new discipline, that of nuclear physics. His original idea of nuclear bombardments made possible the transmutation of chemical elements. Rutherford's research was instrumental in the convening of the Manhattan Project to develop the first nuclear weapons during the Second World War. In 1997, the *rutherford*, a unit of radioactivity, was named in his honour.

RUTHERFORD'S LEGACY

UNDER RUTHERFORD'S supervision at the Cavendish Laboratory at Cambridge, four scientists shared three Nobel Prizes for physics. John Cockroft and Ernest Walton split the atom using a particle accelerator; James Chadwick discovered the neutron and Edward Appleton demonstrated the existence of the ionosphere. Also Otto Hahn, who later discovered atomic fission, worked under Rutherford at the Montreal Laboratory in 1905–6, and in 1921 Niels Bohr worked with him.

GALAXIES BEYOND THE MILKY WAY AND THE UNIFORM EXPANSION OF THE UNIVERSE

—– 1923 *and* 1929 —–

EDWIN POWELL HUBBLE 1889–1953, UNITED STATES

The Hubble Space Telescope, launched in 1990, is named after one of the leading astronomers of the 20th century. After serving in the First World War as a major in the US Army, Hubble was offered a staff position in 1919 at California's Mount Wilson Observatory, which housed the newly commissioned 100-inch (2.5-m) Hooker telescope, then the largest telescope in the world. Most astronomers at this time thought that all the Universe, consisting of the planets, stars and fuzzy objects called nebulae, was contained within the *Milky Way* galaxy. Our galaxy was thus thought to comprise the entire Universe. In 1923 Hubble trained the Hooker telescope on a hazy patch of night sky called the *Andromeda Nebula*, and found that it contained stars just like the ones in our galaxy, only dimmer. One star he saw was a *Cepheid variable*, a type of star with a known, varying brightness that can be used to measure distances. From this measurement Hubble deduced that the Andromeda Nebula was not a nearby star cluster but rather another galaxy, now called the *Andromeda Galaxy*.

In the following years Hubble made similar discoveries, and by the end of the 1920s scientists became convinced that our Milky Way galaxy was only one of billions in the Universe. This shift in thought was as profound in its own way as the realization that the world was round, and that Earth revolved around the Sun. By the end of the 1920s Hubble had discovered enough galaxies to compare them to one another. He then created a system for classifying galaxies into *elliptical*, *spiral* and *barred spiral* according to their appearance, a system called the *Hubble tuning fork diagram*. It is still

used today in an evolved form. He arranged the different groups of galaxies in what became known as the *Hubble sequence*.

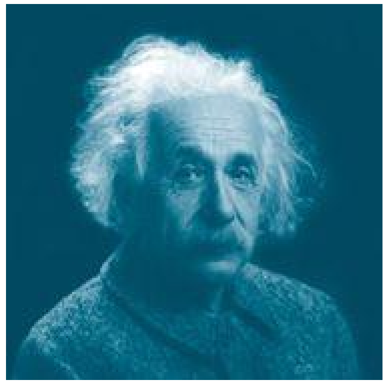
Hubble also made an astonishing discovery from his study of the spectra of 46 galaxies, relating to the Doppler velocities of those galaxies relative to our own Milky Way galaxy. What he found was that the further apart galaxies are from each other, the faster they move away from each other. Based on this observation, Hubble concluded that the Universe is expanding uniformly. Thus the degree of *Doppler shift* or *redshift* seen in the light spectra from other galaxies was shown to increase in proportion to a particular galaxy's distance from Earth. This relationship became known as *Hubble's Law*, helping establish the fact that the Universe is constantly expanding. Hubble's data, published in 1929, was the first observational support for Georges Lemaître's *Big Bang* theory of 1927.

THE HUBBLE STAMP

IN 2008 the United States Postal Service released a 41 cent stamp honouring Hubble. His citation reads: '*Often called a "pioneer of the distant stars," astronomer Edwin Hubble (1889–1953) played a pivotal role in deciphering the vast and complex nature of the universe. His meticulous studies of spiral nebulae proved the existence of galaxies other than our own Milky Way. Had he not died suddenly in 1953, Hubble would have won that year's Nobel Prize in Physics.*'

EINSTEIN'S BIGGEST BLUNDER

IN 1917 Albert Einstein had found that his newly developed *theory of general relativity* indicated that the Universe must be either expanding or contracting. Unable to believe what his own equations were telling him, Einstein introduced the '*fudge factor*' of a '*cosmological constant*' to his equations to avoid this 'problem'. When Einstein heard of Hubble's discovery, he said that changing his equations as he did was '*the biggest blunder of* [his] *life*'.



Hubble and his colleague at Mount Wilson, Milton Humason (who incredibly started work as a mule driver during the construction of the observatory, then served as its janitor, then as a night assistant), estimated the expansion rate of the Universe to be 310 miles (500 km) per second per *megaparsec*. (A megaparsec, or a million parsecs, is a distance equal to about 3.26 million light-years; so a galaxy two megaparsecs away is receding from us twice as fast as a galaxy only one megaparsec away.) This estimate is called the *Hubble Constant*, and scientists have been fine-tuning it ever since. Cosmologists use this measurement to extrapolate back to the Big Bang. They currently estimate the age of our solar system to be 4.5 billion years, and the age of the Universe to be 13.75 billion years. Shortly before his death, Mount Palomar's giant 200-inch (5-m) reflector Hale Telescope was completed, and Hubble was the first astronomer to use it. Hubble continued his research at the Mount Wilson and Mount Palomar Observatories, where he remained active until his death.

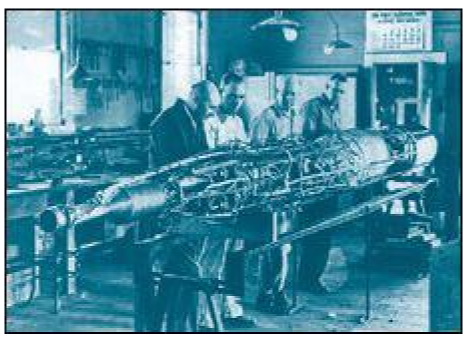
SPACE ROCKET

—— 1926 ——

KONSTANTIN TSIOLKOVSKY 1857–1935, RUSSIA, AND ROBERT HUTCHINGS GODDARD 1882–1945, UNITED STATES

Modern rocketry begins with these two men, whose work pioneered the way to later space exploration. Goddard's work anticipated many of the developments that made spaceflight possible. In 1898 the Russian schoolteacher and scientist Tsiolkovsky first proposed space exploration. In 1903 he suggested using liquid propellants for rockets to achieve greater range, stating that the speed and range of a rocket were limited only by the

exhaust velocity of escaping gases. For his research and vision, Tsiolkovsky has been called ‘the father of modern astronautics’. Goddard was a professor and physicist, conducting practical experiments in rocketry, trying to achieve higher altitudes than were possible for lighter-than-air balloons. In 1919 he published *A Method of Reaching Extreme Altitudes*, a mathematical analysis of what was needed to launch a *sounding rocket* or *research rocket*. These carry instruments to take measurements in sub-orbital flight, the altitude between that occupied by weather balloons and satellites above the surface of the Earth. Goddard’s earliest experiments were with solid-propellant rockets. From 1915, he tried various types of solid fuels, measuring the exhaust velocities of the burning gases. However, like Tsiolkovsky, Goddard became convinced that a rocket could be propelled better by liquid fuel. It was a much more difficult task than building solid-propellant rockets, and no-one had attempted it before. Fuel and oxygen tanks, turbines and combustion chambers were needed. Goddard achieved the first successful flight with a liquid-propellant rocket in 1926. Fuelled by liquid oxygen and gasoline, it flew for only two and a half seconds, climbed 41 feet (12.5 m) and landed 184 feet (56 m) away.



Goddard’s rocket was the forerunner of a new era in rocket flight. His experiments continued for many years, with bigger, higher-flying rockets. In 34 flights, Goddard reached altitudes of up to 1.6 miles (2.6 km) and speeds of up to 550 mph (885 kph). He developed a gyroscope system for flight control, three-axis control, steerable thrust and a payload compartment for scientific instruments. Parachute recovery systems were employed to return rockets and instruments safely. Goddard has been called ‘the father of modern rocketry’. Two of his 214 patents, for a multi-stage rocket design (1915) and for a liquidfuel rocket design (1915), are regarded as important milestones on the road to spaceflight. Goddard received little

public support during his lifetime, and his revolutionary ideas about spaceflight were sometimes ridiculed in the press. Following criticism in *The New York Times*, Goddard responded to a reporter's question with: '*Every vision is a joke until the first man accomplishes it; once realized, it becomes commonplace.*' Goddard shied away from publicizing his work, but he was the first man to recognize the scientific potential of missiles and space travel. He was also the first to master the design and construction of the rockets needed to implement his ideas.

THE CHERRY TREE DREAM

GODDARD BECAME interested in space upon reading H.G. Wells's *War of the Worlds*, aged just 16. In 1889, a year later, he climbed a cherry tree to cut off some dead branches. Goddard was transfixed by the sky, and his imagination took hold of him. He later wrote: '*On this day I climbed a tall cherry tree at the back of the barn … and as I looked toward the fields at the east, I imagined how wonderful it would be to make some device which had even the possibility of ascending to Mars, and how it would look on a small scale, if sent up from the meadow at my feet. I have several photographs of the tree, taken since, with the little ladder I made to climb it, leaning against it. It seemed to me then that a weight whirling around a horizontal shaft, moving more rapidly above than below, could furnish lift by virtue of the greater centrifugal force at the top of the path. I was a different boy when I descended the tree from when I ascended. Existence at last seemed very purposive.*' For the rest of his life Goddard observed 19 October as his 'Anniversary Day', his personal commemoration of the day of his greatest inspiration.

After the Second World War, many unused German V-2 rockets and components were captured by the Allies. German rocket scientists were welcomed in the United States and the Soviet Union. Both superpowers now realized the potential of rocketry as a military weapon and began a variety of experimental programmes. The German rocket scientist Wernher von Braun and others were amazed at the progress Goddard and his small team had made. At first, the United States ran a programme with highaltitude atmospheric 'sounding rockets', one of Goddard's early ideas. Later, a variety of medium- and long-range intercontinental ballistic

missiles were developed. These became the starting point of the US space programme. Missiles such as the *Redstone*, *Atlas* and *Titan* would eventually launch US astronauts into space. On 20 February 1962 an *Atlas* rocket successfully carried John Glenn into orbit aboard his Mercury capsule *Friendship 7*, a flight that ushered in a new era of American space travel that eventually led to Americans walking on the Moon by the end of the 1960s.

MODERN TELEVISION

—– 1927 —–

PHILO TAYLOR FARNSWORTH 1906–1971, UNITED STATES

Farnsworth was the pioneer of the modern world's most popular medium of entertainment and information. In the 1920s the word *television* meant a device that mechanically scanned an image through a spinning disc with holes cut in it. It then projected a tiny, unstable reproduction of what was being scanned onto a screen. In 1926 John Logie Baird had demonstrated this mechanical device. However, Farnsworth imagined instead a vacuum tube that could reproduce images electronically, by shooting a beam of electrons, line by line, against a lightsensitive screen. Aged 20, he managed to obtain some funding for his efforts, and in September 1927 demonstrated the first all-electronic television. He became the first inventor to transmit what we would now call a television image, which comprised 60 horizontal lines. Prophetically, it was of a dollar sign.

Farnsworth had developed the *image dissector tube*, the basis of all later electronic televisions. The patent for this video camera tube was submitted in January 1927. Photocathode emissions create an *electron image*, which is then scanned to produce an electric signal to represent the visual image. He had demonstrated for the first time that it was possible to transmit an 'electrical image' without the use of any mechanical contrivances. Farnsworth had replaced spinning discs and mirrors with the electron itself, an object so small and light that it could be deflected back and forth within a vacuum tube tens of thousands of times per second. Farnsworth was the first to form and manipulate an electron beam, and that accomplishment represents a quantum leap in human knowledge. After 1927, every new contribution to developing television technology was essentially an

improvement upon Farnsworth's profound invention. In 1928 Farnsworth gave the world's first demonstration of a complete, all-electronic television system, including his image dissector, employing electronic scanning in both the pickup and display devices.

In 1930, the same year that Farnsworth secured his patent for an all-electronic televisions, his laboratories were visited by Vladimir Zworykin of RCA, who had invented a television that used a cathode ray tube (1928) and an all-electric camera tube (1929). This led to a patent battle that lasted over ten years, resulting in RCA paying Farnsworth $1 million for patent licences, for TV scanning, focusing, synchronizing, contrast and control devices. During the Second World War, despite the fact that he had invented the basics of radar, black light (for night vision) and an infrared telescope, Farnsworth's company had cash flow problems, and it was sold to ITT in 1949. Farnsworth's 165 other patented inventions include the first 'cold' cathode ray tube, an air traffic control system, a baby incubator, the gastroscope, and the first (although primitive) electronic microscope. From the 1950s until his death his major interest was nuclear fusion, and in 1965 he patented an array of cylindrical tubes, called *fusors*, that produced a 30-second fusion reaction.

FARNSWORTH, THE BOY GENIUS

IN 1922 the 16-year-old Farnsworth sketched out for his baffled chemistry teacher, Justin Tolman, his idea for an *image dissector* vacuum tube that could revolutionize television. The boy believed that electricity could be transformed into pictures by controlling the speed and direction of fast-flying electrons. His amazed teacher kept the drawing.

BIG BANG THEORY

—— 1927–1930 ——

GEORGES LEMAÎTRE 1894–1966, BELGIUM

Georges Henri Joseph Édouard Lemaître was a part-time lecturer at the Catholic University of Louvain (Leuven) in Belgium when he published a 1927 paper called '*A homogeneous Universe of constant mass and growing radius accounting for the radial velocity of extragalactic nebulae*'. In this sensational publication he presented what came to be known as the *Big Bang* theory of an expanding Universe. He also derived Hubble's Law and gave the first observational estimation of the Hubble Constant. Two years later, Hubble proved Lemaître's theory, publishing his velocitydistance relation that strongly supported an expanding Universe, and consequently the Big Bang theory. Hubble had used Lemaître's general relativity formulae to prove that objects in deep space exhibit a Doppler shift velocity relative to Earth and to each other. The Belgian paper had little impact, and Einstein refused to accept the idea of an expanding Universe.

DARK MATTER, DARK ENERGY, DARK FLOW AND MULTIPLE UNIVERSES

IT WAS formerly thought that the expansion of the Universe had been slowing down since the Big Bang more than 13 billion years ago. After the Big Bang, the laws of physics tell us that cooling of the original Universe would cause blocks of matter to form and gravity would start taking effect. Scientists currently know of 24 particles, each with different characteristics; to explain the constantly expanding Universe, they have postulated that there is a substance called *dark matter*, made up of 24 unknown particles of matter. We cannot see or measure dark matter, as it does not emit or reflect light, but it is estimated that there is five times as much of it as 'normal' matter in the Universe. The 24 unknown particles can pass through stars, and it will be difficult to measure them as they will pass through any measuring equipment. It is thought that dark matter creates gravity to form galaxies.

However, the Hubble Space telescope has found out that not only is the Universe expanding (due to dark matter), but the expansion is *accelerating*.

In 2011 three physicists were awarded the Nobel Prize in Physics, having discovered in 1998 that exploding stars in deep space are moving away far faster than expected because something is overriding gravity. The mysterious force causing this acceleration is not understood, and is named *dark energy*. The pull of gravity should be acting as a brake upon any expansion, but is not. Dark energy is a new force powering the Universe, and pulling it apart. The more the Universe expands, the more dark energy expands to fill the gaps. Thus there is no such thing as an empty vacuum in space, even if all the known and unknown particles were to be removed. Space is full of a mysterious type of energy which we do not understand.

This would be a difficult enough concept to understand, but there is a new phenomenon to consider. There are distortions in light emitting from cosmic microwave radiation. Whole clusters of galaxies are moving in an unexpected way, known as *dark flow*. Patches of matter in the Universe seem to be moving at very high speeds and in a uniform direction that cannot be explained by any of the known gravitational forces in the observable cosmos. The stuff that's pulling this matter must be outside the observable Universe, researchers conclude. The only explanation is that our Universe is part of a larger whole – there are a number of *pocket universes* created by inflation.

In 1930 the noted astrophysicist Arthur Eddington (1882–1944) wrote of his former student that Lemaître's article was a '*brilliant solution*' to the outstanding problems of cosmology. Lemaître was at last taken seriously. He was invited to London and proposed to the British Association that the Universe had expanded from an initial point, the *Primeval Atom*. He called his theory '*the Cosmic Egg exploding at the moment of the creation*'. It was later termed the *Big Bang* theory by the astronomer and mathematician Fred Hoyle (1915–2001), when he rejected it disparagingly on BBC radio in 1949. Lemaître met Einstein several times, gradually coming to the conclusion that Einstein's own static model of a Universe could not be sustained indefinitely looking back into the past. In 1935 at a Princeton seminar, Lemaître expounded his theory, and Einstein applauded '*the most beautiful and satisfactory explanation of creation to which I have ever listened.*' Lemaître had explained that cosmic rays were the residual effects of the initial *explosion*. He died shortly after learning of the discovery of cosmic microwave background (CMB) radiation, which proved his theory.

PENICILLIN

—— 1928 ——

DANIEL MERLIN PRYCE 1902–1976, WALES AND ENGLAND

Penicillin was one of the first and most widely used antibiotic agents, and has saved millions of lives. Merlin Pryce had been employed as a research assistant to Professor Alexander Fleming (1881–1955), but in February 1928 he moved on to research in other areas. According to Mrs Hilda Jarman, Pryce's sister, Fleming went on holiday that summer. Pryce called in to say hello to his friend on Fleming's first day back at work, and noticed blue-green mould on one of the unwashed *Staphylococcus aureus* culture dishes in the laboratory. The mould was less than an inch (2.5 cm) across, with a ring around it where *Staphylococcus* bacteria had died. Penicillin is derived from Pryce's discovery of the *Penicillium notatum* mould. Fleming was not a chemist and could neither isolate the active antibacterial element, penicillin, nor keep the element active long enough to be used medicinally in humans. In 1929, Fleming wrote a paper describing his findings, but the discovery was largely forgotten.

THE UNKNOWN PIONEER

THE PENICILLIN antibiotic is estimated to have saved over 80 million lives and led to the development of other antibiotics, because of the pioneering work of the British chemist and crystallographer Dorothy Mary Hodgkin (1910–1994). She used X-rays to discover the structural layouts of atoms and the overall molecular shape of more than 100 molecules, including penicillin. Hodgkin advanced the techniques of X-ray crystallography, and for her work on the structure of penicillin and vitamin B12, she received the Nobel Prize in Chemistry (1964). In 1969, after 35 years research, Hodgkin managed to decipher the structure of insulin hormone crystals, which is of enormous importance in the treatment of diabetes.

In 1940 scientists at Oxford University were researching promising projects in bacteriology that could possibly be enhanced or continued by means of chemistry. Using new chemical techniques, Howard Florey, Ernst Chain and Norman Heatley worked with the *Penicillium* mould, isolating its

active ingredient. They then developed a brown powder, *penicillin*, which kept its antibacterial power for longer than a few days. Needing the new drug immediately for the war front, mass production started quickly. The availability of penicillin during the Second World War saved many lives that otherwise would have been lost due to bacterial infections in even minor wounds. Penicillin also treated diphtheria, gangrene, pneumonia, syphilis and tuberculosis. Florey and Chain jointly received the Nobel Prize in Physiology or Medicine with Fleming in 1945, but Heatley was sadly overlooked. Antibiotics are natural substances that are released by bacteria and fungi into their environment, as a means of inhibiting other organisms such as disease-causing bacteria. Penicillin antibiotics are enormously significant because they were the first drugs proven to be effective against many previously serious diseases such as syphilis and infections caused by *staphylococci* and *streptococci*, but many types of bacteria are now evolving to be resistant to penicillin.

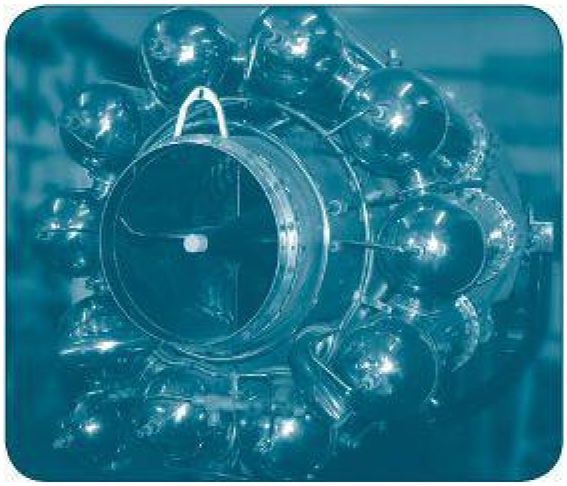
JET ENGINE

—— 1930 ——

FRANK WHITTLE 1907–1996, ENGLAND

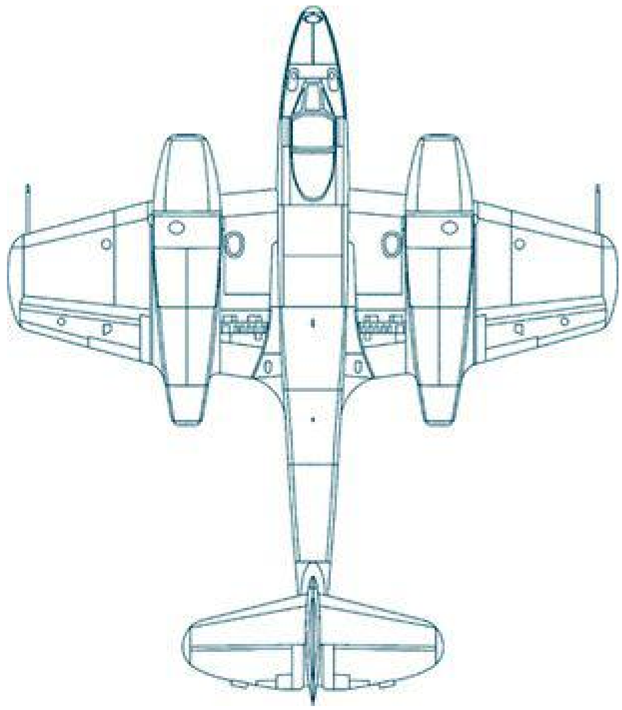
The jet engine transformed both global travel and aerial warfare, and it has allowed millions of people to cross the world at speed. In the 1920s a young RAF engineer, Frank Whittle, presented a design for a jet engine to Britain's Air Ministry, but it rejected his idea. Undaunted, Whittle patented his *turbojet engine* in 1930. His design appeared to solve the problem of creating a chamber strong enough to house an engine that created incredible heat and huge directed thrust. Single combustion chambers were simply too weak, producing a volatile and potentially uncontrollable reaction, and they could explode under the strain. However, Whittle's engine divided up the combustion into ten chambers, producing impressive thrust while not decreasing the power of the engine. In 1936 Whittle set up a company called Power Jets Ltd. Increasing fears about potential war in Europe had led the government to reconsider the value of Whittle's jet engine. In 1937, using newly available lighter and stronger alloys, Whittle produced the first viable jet engine to be successfully tested in a laboratory. Whittle struggled to get enough government funding to develop it further, but in 1941 a new

jet fighter prototype flew. Its successor, the *Gloster Meteor*, entered service with the RAF in 1944. However, the Gloster Meteor was not the first jet fighter to take to the air, as Germany's *Heinkel He 178* first flew in 1939, days before the outbreak of the Second World War.



WHITTLE AND GENIUS

IN SEPTEMBER 1935 Frank Whittle was introduced to two investment bankers, Sir Maurice Bonham-Carter and Lancelot Law Whyte, as he was attempting to finance his new company, Power Jets Ltd. Their firm had an interest in developing speculative projects that conventional banks would not assist. Whyte was impressed by the 28-year-old Whittle and his design: '*The impression he made was overwhelming, I have never been so quickly convinced, or so happy to find one's highest standards met … This was genius, not talent. Whittle expressed his idea with superb conciseness: "Reciprocating engines are exhausted. They have hundreds of parts jerking to and fro, and they cannot be made more powerful without becoming too complicated. The engine of the future must produce 2,000 hp with one moving part: a spinning turbine and compressor"*.' Lee Payne, '*The Great Jet Engine Race … And How We Lost*', *Air Force Magazine*, January 1982



Whittle’s company was nationalized after the war, but Whittle suffered a breakdown caused by exhaustion and overwork. His new invention was now applied to passenger planes, which allowed for quicker journeys on much larger aircraft. The first jet-engined passenger airliner was the *De Havilland DH 106 Comet* in 1949. Within two years, it was withdrawn from service after a series of tragic accidents, due to metal fatigue in its fuselage which led to the aeroplane breaking up in flight. It was redesigned and continued in service for another 30 years. Other manufacturers learned from the Comet’s mistakes and the US company Boeing then took over the lead in jetpowered airliners. The *Boeing 707* entered service in 1958. It was safe and allowed people to travel distances at speeds that would had been impossible just ten years earlier. Now Airbus and Boeing virtually monopolize large passenger aircraft production. Whittle’s invention has transformed the world.

SUPERMARKET

—— 1930 ——

MICHAEL J. CULLEN 1884–1936, UNITED STATES

The advent of the supermarket brought about a revolution in retailing, transforming shopping habits across the world. The child of Irish immigrants, Cullen worked in retail and joined the Cincinnati-based Kroger Stores in 1919, and working for them until 1930. During this period he developed the idea of a supermarket, writing a letter to the president of Kroger in which he proposed a new type of food store with a focus on low prices, self-service, larger square footage, cash sales, no delivery service and low rent locations with plenty of free parking. Free parking allows for larger purchases to be made and transported home easily. Cullen suggested that this new type of store could achieve nearly ten times the volume and profits of the average Kroger or A&P store, but his letter went unanswered. Clarence Saunders with his *Piggly Wiggly* chain had introduced self-service, uniform stores and nationwide marketing from 1916 onwards, but Cullen built on this idea by adding separate food departments, selling large volumes of food at discount prices and adding lots of dedicated parking space. Cullen resigned from Kroger and moved his family to Long Island, New York to launch his own store. He leased a vacant garage in Queens, a few blocks from a busy shopping district. In 1930 he opened his *King Kullen* Grocery Company, and this is recognized by the Smithsonian Institution as the world's first supermarket. His store carried a range of around 1000 items, including automotive accessories and hardware as well as groceries. Customers came from miles around, as Cullen offered convenient and affordable food. Newspaper advertisements promoted the store as the '*World's Greatest Price Wrecker*', and new stores operated under the slogan '*Pile it high. Sell it low.*'

HYPERMARKETS

A HYPERMARKET is a superstore which combines a supermarket and a department store, carrying not only full grocery lines but general merchandise. Fred Meyer of Oregon was the first one-stop shopping centre in 1931. It included a grocery store alongside a chemist, plus home products, off-street parking, a petrol station, and later clothing. In 1962 Meijer (the brainchild of Dutch immigrant Hendrik Meijer) opened its first hypermarket in Michigan, named *Thrifty Acres*. In France, Carrefour opened its first such store in 1963. The hypermarket concept blossomed in the United States in 1987, both with the introduction of stores by Carrefour

and by other major American chains. In the late 1980s and early 1990s, the three major discount stores of Wal-Mart, Target and Kmart started developing the hypermarket format. In theory, hypermarkets allow customers to satisfy all their routine shopping needs in one trip. They cover large areas, normally on one floor, with a typical Wal-Mart Supercenter covering from 150,000 square feet (13,935 sq m) to 235,000 square feet (21,830 sq m), and a typical Carrefour around 210,000 square feet (19,500 sq m). Because of the need for hundreds of shoppers to carry away large quantities of goods, they are usually found in out-of-town or suburban locations, and are easily accessible by car.

Cullen's chain expanded rapidly during the Great Depression, reusing large older buildings, including abandoned factories and warehouses. He always chose low-rent locations with free parking on the borders of well-populated areas. Service was minimal as customers helped themselves by loading goods into their shopping carts. National brands were emphasized. By 1936 there were 17 King Kullen supermarkets bringing in revenues of around $6,000,000 annually. Cullen planned faster national expansion and franchising, but he died suddenly following an appendix operation, aged only 52. Other grocery store retailers such as Safeway and his former employer Kroger imitated his success, and by 1934 there were 94 supermarkets in the United States. Kroger took Cullen's idea one step further and pioneered the first supermarket surrounded on all four sides by parking spaces. By 1936, the year of Cullen's death, there were 1200 supermarkets in 85 cities. By 1950 the number had increased to 15,000 and the supermarket concept began to spread to Britain and other countries.

NUCLEAR FISSION

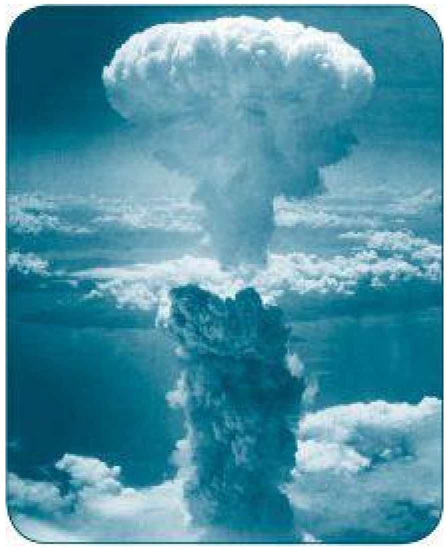
— 1934 —

ENRICO FERMI 1901–1954, ITALY AND UNITED STATES

Known along with Robert Oppenheimer (1904–1967) as ‘the father of the atomic bomb’, Fermi is also responsible for the design of nuclear reactors. In 1933 Fermi developed the theory of *beta decay*, postulating that the newly-discovered neutron, decaying to a proton, emits an electron and a particle which he called a *neutrino*. The theory developed to explain this interaction later resulted in recognition of his *weak* interaction force. From 1934, at the University of Rome, Fermi began bombarding various elements with neutrons. He found that this was effective in producing radioactive atoms, but did not realize at that time that he had ‘split the atom’, believing that he had instead discovered elements beyond uranium. By 1935 Fermi and one of his colleagues in Rome, Emilio Segrè, had discovered *slow neutrons*, which have properties important to the operation of nuclear reactors. Fermi won the Nobel Prize in Physics for his work on induced radioactivity in 1938. With his Jewish wife, he was forced to escape Fascist Italy and move to the USA in 1938, continuing his work on nuclear fission there.

It was now recognized that nuclear fission (the splitting of the atom) had taken place in Fermi’s laboratory and in other experiments in Germany. With the Second World War raging in Europe, the ability to produce an *atomic bomb* based upon nuclear fission was of the greatest importance to the balance of world power. Fermi thus supervised the design and assembly of what he called an *atomic pile*, which in peacetime would be known as a *nuclear reactor*. On 2 December 1942 Fermi achieved the first self-sustaining chain reaction, and thereby initiated the controlled release of nuclear energy. His chain-reacting pile helped scientists to understand the internal workings of an atomic bomb, and acted as a pilot plant for the massive reactors which had to be built to produce plutonium. This initiated the *Atomic Age* and Fermi joined the *Manhattan Project* in 1943. His team moved to New Mexico and on 16 July 1945 the first atomic bomb was successfully detonated there as part of the Manhattan Project, followed by detonations of a *uranium bomb* at Hiroshima and a *plutonium bomb* at Nagasaki. Fermi carried on research at the University of Chicago, doing important work in the fields of quantum mechanics, nuclear physics, particle physics and statistical mechanics. He is regarded as one of the

leading scientists of the 20th century, the only man accomplished in both theory and experiment. He died aged 53 from stomach cancer, probably brought on by his experiments with radioactivity. *Fermium*, the 100th element in the periodic table, is named after him.



FERMI ON THE HYDROGEN BOMB

'*SUCH A weapon goes far beyond any military objective and enters the range of very great natural catastrophes. By its very nature it cannot be confined to a military objective but becomes a weapon which in practical effect is almost one of genocide. It is clear that the use of such a weapon cannot be justified on any ethical ground which gives a human being a certain individuality and dignity even if he happens to be a resident of an enemy country … The fact that no limits exist to the destructiveness of this weapon makes its very existence and the knowledge of its construction a danger to humanity as a whole. It is necessarily an evil thing considered in any light.*' Fermi submitted this addendum to the General Advisory Committee Report for the Atomic Energy Commission, 30 October 1949. The USA exploded its first hydrogen thermonuclear bomb in 1952 and the Russians in 1953.

REVOLUTION IN ECONOMIC THOUGHT

— 1936 —

JOHN MAYNARD KEYNES 1883–1946, ENGLAND

Many believe that Keynes's work ensured the survival and growth of capitalism as the world's leading economic model. During the First World War Keynes was an advisor on overseas finances to the Treasury in London, and helped to balance France's accounts by asking Britain's National Gallery to buy paintings by Manet, Corot and Delacroix at bargain prices. After the war, Keynes was selected to be a delegate to the Paris Peace Conference of 1918–19. The Allied leaders Woodrow Wilson, David Lloyd George and Georges Clemenceau imposed vindictive war reparations on Germany, and Keynes's violent disagreement with their actions triggered his short book, *The Economic Consequences of the Peace*. He knew that Germany could not possibly pay off their financial burden, and that it would have serious consequences, fostering German resentment and threatening any lasting peace. His best-selling book made Keynes world-famous. In the 1920s and 1930s the Great Depression led to one in four men being unemployed in America and Europe. Keynes proselytized for governments to borrow money and spend their way out of recession, thus creating demand. Most economists disagreed. In 1932 F.D. Roosevelt became president of the United States by promising to balance the budget, rather than run a deficit as President Hoover was doing. Keynes argued with Roosevelt, and as the Depression wore on and war loomed, Roosevelt at last tried investing in public works, farm subsidies and other devices to successfully restart the economy.

Keynes's greatest influence came from his 1936 book *The General Theory of Employment, Interest and Money*. He argued that in order to keep people fully employed, governments have to run deficits when the economy is slowing, as the private sector will not invest enough. As their markets become saturated, businesses reduce their investments, setting in motion a dangerous cycle: less investment, fewer jobs, less consumption and even less reason for business to invest. The economy may reach perfect balance, but at a cost of high unemployment and social misery. It would be better for governments to avoid the pain in the first place by taking up the slack. In 1938 F.D.R. at last fully embraced Keynesianism, telling the American people '*We suffer primarily from a failure of consumer demand because of a lack of buying power*', so the government had to '*create an economic*

upturn’ by making ‘*additions to the purchasing power of the nation*’. This is exactly what Germany and Italy had been doing with large scale public works, and their economies were once again thriving as a result.

HOW TO MAKE FRIENDS AND INFLUENCE PEOPLE

In his *The Economic Consequences of the Peace* (1919), Keynes disparaged the three most important world leaders of the time. He called Woodrow Wilson a ‘*blind, deaf Don Quixote*’. To Keynes, Clemenceau was a xenophobe with ‘*one illusion – France, and one disillusion – mankind’*. He called Lloyd-George *‘this goat-footed bard*, *this halfhuman visitor to our age from the hag-ridden magic and enchanted woods of Celtic antiquity*’ (i.e. Wales).

When the United States entered the Second World War, Roosevelt had no option but to experiment with Keynes’s idea on a scale necessary to pull the nation out of recession. Between 1939 and 1944 (the peak of wartime production), the nation’s output almost doubled, and unemployment fell from 17 per cent to around 1 per cent. Never before had an economic theory been so dramatically tested and proved. America’s Employment Act of 1946 codified the new thinking, making it ‘*the continuing policy and responsibility of the Federal Government … to promote maximum employment, production, and purchasing power.*’ This the Federal Government did, for the next quarter-century. It became accepted wisdom that government could *fine-tune* the economy, pushing the twin accelerators of fiscal and monetary policy in order to avoid slowdowns, and applying the brakes when necessary to avoid overheating. At the end of the Second World War, the USA and Britain agreed that lasting peace could best be maintained if the defeated powers of Japan, Germany and Italy were helped

to rebuild. Massive public investment would create trading partners that would have the capacity to buy the victors' exports, and also build solid middle-class democracies in those countries. In 1964 Lyndon Johnson cut taxes to expand purchasing power and boost employment. '*We are all Keynesians now,*' Richard Nixon famously proclaimed.

However, the *free market* theories followed by Mrs Thatcher and President Reagan have been adopted all over the world, with governments allowing the markets to rule themselves, Keynes's theories are no longer pursued. Thus we are seeing multinational companies becoming more powerful than governments, literally controlling economic policies, and a return to recessional cycles. Now the controlled economy of China offers a better business model that the liberal economic one. Politicians do not seem to understand that there is no such thing as a 'free market' or 'law of the markets' or 'market forces'. Markets do not work themselves, but are influenced by money traders and speculators who forwardpurchase and gamble upon crop yields, country deficits, bank failures and the like. Liberal economics can only work if people who influence outcomes are taken out of any equation. Governments need to control economies beneficially once more, but because of the networked interrelationships of countries and economic unions and the power of financial trading, it is no longer possible.

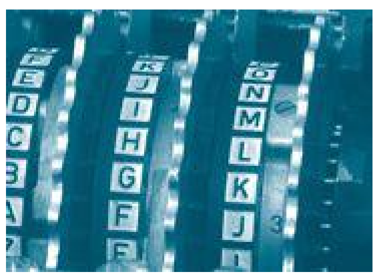
TURING MACHINE

—— 1936–1937 ——

ALAN MATHISON TURING 1912–1954, ENGLAND

Turing was the man who first conceptualized computer programming, and is known as 'the father of computer science and artificial intelligence'. Turing studied at Cambridge University, working in the field of quantum mechanics. Here, he developed the mathematical proof which states that automatic computation cannot solve all mathematical problems. This concept, also known as the *Turing Machine,* is the basis for the modern theory of computation. He conceptualized an imaginary machine like a typewriter capable of scanning, or reading, instructions encoded on a tape of theoretically infinite length. Turing demonstrated that the output of the machine could replicate logical human thought, as the scanner moved from

one square of the magnetic tape to the next, responding to the sequential commands and modifying its mechanical response if so ordered. Turing then hypothesized that since the instructions on the tape governed the behaviour of the machine, by changing those instructions, one could induce the machine to perform the functions of all such machines. In other words, depending on the tape it scanned, the same machine could calculate numbers or play chess or do anything else of a comparable nature. Hence his device acquired the new name of the *Universal Turing Machine*. This we recognize as the process used by today's computers, but it was a revolutionary concept at the time – hardware performing complicated and multifaceted tasks according to the instructions fed to it. He published his seminal theory in '*On Computable Numbers, with an Application to the Entscheidungsproblem*' (1936–7), but no one at the time recognized that Turing's machine provided a blueprint for what would eventually become the electronic digital computer. Today, everyone who taps at a keyboard, using a spreadsheet or a word-processing program, is working on a Turing machine.



THE HALTING PROBLEM

TURING'S 1936–7 paper was enormously influential in computer science in two ways. Its primary purpose was to prove that there were problems (namely the '*halting problem*') that could not be solved by any sequential process. The halting problem could be stated as follows: '*Given a description of a computer program, decide whether the program finishes running or continues to run forever. This is equivalent to the problem of deciding, given a program and an input, whether the program will eventually halt when run with that input, or will run forever.*' Turing proved that a general algorithm to solve the halting problem for all possible program-input pairs cannot exist. A key part of the proof was a

mathematical definition of a computer and program. Except for the limitations imposed by their finite memory stores, modern computers are said to be ‘Turing-complete’, i.e. they have algorithm execution capability equivalent to a universal Turing machine.

SUICIDE OF A GENIUS

In 1952 Turing was arrested and tried for homosexuality, then a criminal offence, and convicted of gross indecency. To avoid prison, he accepted hormonal treatment involving injections of oestrogen for a year, which were intended to neutralize his libido. ‘*I’m growing breasts!*’ Turing told a friend. Turing’s security clearance was withdrawn, as he was potentially a target for blackmail. This meant that he could no longer work for GCHQ, the successor to Bletchley Park. He committed suicide aged just 41, by eating an apple laced with cyanide.

When the war started, Turing left America for England, and then led a cryptoanalytic team at Bletchley Park, the code-breaking establishment in Buckinghamshire. His team helped to design a computer-like machine that decoded at high speed German messages encrypted on their U-boats’ *Enigma* code machines, thus helping to win the Second World War. From 1945 to 1948 Turing worked at the National Physical Laboratory in Teddington, near London, having been promised that he could develop a machine that would logically process information. It is thought that Turing’s blueprint of a machine capable of very fast computation speeds would have led to the world’s first digital computer, but bureaucracy left him disillusioned and he left NPL to direct the computing laboratory at Manchester University. Here Turing developed one of the first stored-program digital computers in the world. He influenced the development of computer science, formalizing the concepts of an *algorithm* and computation. Algorithms are sets of well-defined instructions for calculating a function, and are necessary for calculation, data-processing and automated reasoning. Turing was the first man to conceptualize the modern computer. However, the notion of a computer as a general purpose machine, more than a calculator used for solving difficult but specific problems, did not take root until several years after Turing’s death.

PHOTOCOPIER (XEROGRAPHIC PROCESS)

—— 1938 (*first copy*) —— *and* 1942 (*patent*)
CHESTER FLOYD CARLSON 1906–1968, UNITED STATES

Xerography is a foundation stone of a gigantic worldwide copying industry, including multi-functional copiers and duplicators producing billions of copies each year. With degrees in physics and law, Carlson struggled to find work in the Depression, but was eventually promoted to be manager of Bell Telephone Company's patent department in New York. His work as a patent analyzer required him to spend hours going over documents and drawings, preparing the paperwork which was submitted to the patent office to register his company's inventions and ideas. However, the patent office required multiple copies which he had to duplicate by hand. Redrawing the copies took many hours, and Carlson was nearsighted and had arthritis, which made his job even more difficult. He worked constantly in the kitchen of his home to find an alternative solution. He quickly decided not to research in the area of conventional photography, where light is an agent for chemical change, because that phenomenon was already being exhaustively explored in the research labs of large corporations. He had an idea for a reproduction technique based on photoconductivity, as he knew that when light strikes a photoconductive material, the electrical conductivity of that material is increased.

THE PROBLEM OF FORGERY

TODAY'S colour copiers are so technically excellent that to prevent counterfeiting, Xerox colour copiers will print a small pattern of dots to identify the machine. In this way, federal agents can discover the origin of the counterfeit print.

In 1938 he filed for a patent, based upon the principles of what he called *electrophotography* and a month later obtained his first *dry copy*. Photocopiers use toner, which is a mixture of plastic granules, oxide, pigment and wax. The granules accept a photostatic charge and are attracted to a photosensitive drum. This drum transfers images to paper. The toner is then sealed to the paper using a heat process. He said '*I knew that I had a*

very big idea by the tail, but could I tame it?' His patent was issued in 1942 for '*Electrophotography: Forming an image by the action of light on a specially coated charged plate; the latent image is developed with powders that adhere only to electrically charged areas.*'

Between 1939 and 1944 Carlson's invention was turned down by more than 20 companies. He related: '*Some were indifferent, several expressed mild interest, and one or two were antagonistic. How difficult it was to convince anyone that my tiny plates and rough image held the key to a tremendous new industry. The years went by without a serious nibble … I became discouraged and several times decided to drop the idea completely. But each time I returned to try again. I was thoroughly convinced that the invention was too promising to be dormant.*' It took him another 20 years to have his invention marketed, having been turned away from companies like IBM, General Electric and RCA. In 1960 the Haloid Company brought Carlson's idea to market, after 16 years of development. The company was later renamed Xerox, as xerography means *dry writing* in Greek. During the first eight months of production, Haloid sold more copiers then they expected to sell in the product's entire life cycle. Their *914* office copier could make copies quickly at the touch of a button on plain paper, and was a phenomenal success. The world's fastest photocopier developed for office use is capable of making over 150 copies per minute. For commercial copies, there are roll fed machines which top over 300 impressions per minute. (*Wet* copies are made by the later invention of inkjet printers. Ink is distributed on the paper through the use of tiny jets which push the liquid in a series of pulses.) In the remaining eight years of his life, Carlson gave away most of his fortune, donating around $100 million to various foundations and charities.

HELICOPTER

—— 1939 ——

IGOR IVANOVICH SIKORSKY 1889–1972, RUSSIA AND UNITED STATES

Sikorsky is often called 'the father of helicopters' because he invented the first successful rotorcraft in 1939. Heinrich Focke in Germany and Louis Breguet in France were also helicopter pioneers, but Sikorsky is the man who made the technology work. After studying engineering in Paris,

Sikorsky returned to Russia in 1909, designing and testing his first helicopter in that year. However, he said: '*I had learned enough to recognize that with the existing state of the art, engines, materials, and – most of all – the shortage of money and lack of experience … I would not be able to produce a successful helicopter at that time.*' He then concentrated upon an incredibly successful career in developing fixed-wing aircraft. After the First World War, Sikorsky left for the USA, where he designed and built aeroplanes. In the following years, Sikorsky kept returning to helicopter technology, patenting several designs. In 1938, as parent company United Aircraft was closing down Sikorsky's subsidiary to cut costs, Sikorsky received permission to expand his helicopter research and to begin work on an experimental vehicle. In spring 1939 he designed the *Vought-Sikorsky VS-300*, which was built that summer. It pioneered the rotor configuration used by most helicopters today.

Sikorsky's *VS-300* was significant because it was the first working helicopter that did not require two counter-rotating rotors to cancel out torque, instead using a tail rotor that provided thrust in the opposite direction to the torque generated by the main rotor. This made the craft less complicated, lighter and easier to control. But perhaps more importantly, the *VS-300* served as the forerunner for the modern helicopter. In 1941 he created a world record by keeping *VS-300* in the air for 1 hour 32 minutes. Sikorsky then modified the design to produce the prototype Sikorsky *XR-4*, which became the world's first mass-produced helicopter in 1942, entering service with the US Army and Navy in 1943 as the *R-4*. The *R-4* was followed by a succession of bigger and better machines and, since then, the helicopter has clearly established its ability to perform a myriad of difficult missions, including the saving of thousands of lives, in both peacetime and during war.

POLYESTER

—— 1941 ——

JOHN REX WHINFIELD 1901–1966 AND JAMES TENNANT DICKSON (NOT KNOWN), ENGLAND

Among its multiple uses, around half of the world's cloth and clothing is made from this versatile plastic. These two textile chemists invented and patented the first polyester fibre in 1941 in England, and it surpassed nylon in toughness and resilience. Due to wartime secrecy restrictions the invention was not made public until 1946. In the UK, ICI produced it as *Terylene*, and in the USA Dupont called it *Dacron*. Whinfield and his assistant Dickson were investigating polymers with textile fibre potential, discovering how to condense terephthalic acid and ethylene glycol to make a polymer which could be drawn into a fibre. Polyester is a term that can be defined as '*long-chain polymers chemically composed of at least 85% by weight of an ester and a dihydric alcohol and a terephthalic acid*'. In other words, it means the linking of several esters within the fibres. Reaction of alcohol with carboxylic acid results in the formation of esters.

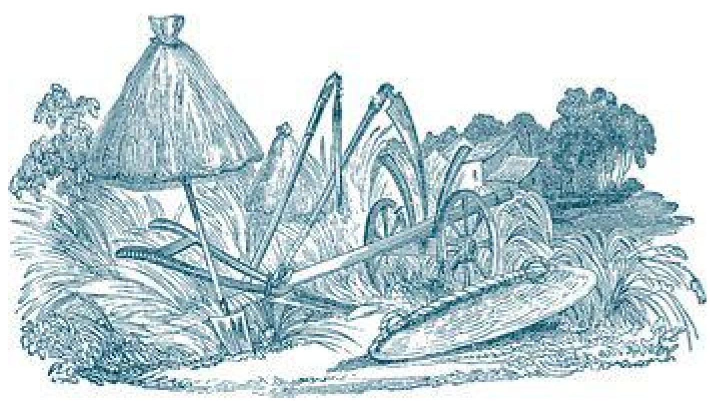
Polyesters are used in reinforced plastics, and are the most widely used and economical family of resins. Polyester fabrics and fibres are extremely strong and durable. They are resistant to most chemicals, do not stretch or shrink, are wrinkle resistant, and also mildew and abrasion resistant. A polyester is hydrophobic in nature and quick drying. It can be used for insulation by manufacturing hollow fibres. Polyester retains its shape and hence is good for making outdoor clothing such as fleeces for harsh climates. It is easily washed and dried, and used as film for food protection. Due to its strength and tenacity, polyester is used to make ropes in industries. PET (polyethylene terephthalate) bottles are today one of the most popular uses of polyester. Polyester, which is hardwearing, is also very extensively used in carpet manufacturing in both spun and filament construction.

GRAIN MODIFICATION, GREEN REVOLUTION

—— 1943 *onwards* ——

NORMAN ERNEST BORLAUG 1914–2009, UNITED STATES

Borlaug has saved a billion lives through modifying cereals. The littleknown agronomist, microbiologist and humanitarian has been called ‘the father of the Green Revolution’ and is one of only six people to have been awarded the Presidential Medal of Freedom, the Congressional Gold Medal and the Nobel Peace Prize. Borlaug developed high-yielding varieties of wheat, allied with modern agricultural methods in Mexico, Pakistan and India, for which he was awarded the Nobel Prize in 1970. Mexico became a net exporter of wheat by 1963, and yields in Pakistan and India nearly doubled, a process then known as the *Green Revolution*. His Nobel award cited his contributions to securing world peace through increasing food supplies. In his 1970 Nobel Lecture, Borlaug pointed out the *Population Monster*, forecasting a world population rising from 3.7 billion to 6.5 billion by 2000. It did exactly that, and passed 7 billion in 2011. (On the website www.worldometers.info, one can watch the world population rising by around 150 people per minute.) Borlaug’s development of new cereal strains were what he called ‘*a temporary success in man’s war against hunger and deprivation*’, a breathing space in which to deal with the Population Monster and the consequent environmental and social ills leading to conflict.



BORLAUG TRIBUTE

‘*IF OVERPOPULATION anarchy comes, it is likely to arrive first in Africa. Borlaug understands this, and is using his remaining years to work against that cataclysm. The odds against him seem long. But then, Norman Borlaug has already saved more lives than any other person who ever lived.*’

Atlantic Magazine, January 1997

Borlaug also advocated increasing crop yields as a means to curb deforestation, the ‘Borlaug hypothesis’ being that ‘*increasing the productivity of agriculture on the best farmland can help control deforestation by reducing the demand for new farmland*’. More than anyone else, Borlaug is responsible for the fact that, throughout the post-war era, global food production has expanded faster than the human population, averting the mass starvations that were widely predicted. The world’s 1950 grain output of 692 million tons (703 million tonnes) came from 1.7 billion acres (688 million ha) of cropland, and the 1992 output of 1.9 billion tons (1.93 billion tonnes) from 1.73 billion acres (700 million ha), a 170 per cent increase from 1 per cent more land. The 1967 bestseller by William and Paul Paddock *Famine – 1975! America’s Decision: Who Will Survive?* informs us that Borlaug’s form of intensive agriculture may have prevented a billion deaths. Borlaug has argued that by producing more food from less land, high-yield farming will preserve Africa’s wild habitats, which have been depleted by slash-and-burn low-yield subsistence agriculture.

STREPTOMYCIN

—— 1943 ——

SELMAN ABRAHAM WAKSMAN 1888–1973, UKRAINE AND UNITED STATES

Streptomycin was the first antibiotic that was used as an active remedy against tuberculosis (TB). Born in the Ukraine, Waksman left for America in 1910, where became a leading biochemist and microbiologist. His detailed research into organic substances (mainly into organisms which live in the soil) and their decomposition led to the discovery of over 20 important new *antibiotics*, a word which he coined himself. His research procedures have been extensively copied, leading to many new discoveries. Professor Waksman’s fields of work include, in chronological order, the microbiological population of the soil; sulphur oxidation by bacteria, microorganisms and soil fertility; decomposition of plant and animal residues, and the nature and formation of humus; occurrence of bacteria in the sea and their role in marine processes; production and nature of antibiotic substances; taxonomy, physiology and biochemistry of the *actinomycetes* (a class of antibiotics isolated from soil bacteria).

CONSUMPTION OR THE KING’S EVIL

THESE ARE both old terms for tuberculosis (TB), along with scrofula, phthisis, white plague and the wasting disease. It was called *consumption* because it seemed to consume people from within, with symptoms including a pallor, fever, bloody cough and long relentless wasting. It was thought that the touch of a king could cure it, hence the name *King’s Evil*. One third of the world’s population is thought to be infected with *Mycobacterium tuberculosis*, with new infections occurring at a rate of about one per second. It can lie dormant in the body for many years, and only about 10 per cent of those people who are infected ever develop the disease.

In 1815 one in four deaths in England was caused by consumption (TB); even by 1918 one in six deaths in France were still caused by the disease. In the 20th century, tuberculosis killed around 100 million people. In the 1880s it was established that the disease was contagious, and there were campaigns to stop people spitting in public places. Sanatoria were established in isolated places to try and stop the spread of the disease, and patients were encouraged to eat well, work outdoors and enjoy exposure to sunlight and fresh air. However, even under the best conditions, 50 per cent of those who entered sanatoria were dead within five years. The proportion of people who become sick with tuberculosis each year is currently stable or even falling worldwide but, because of population growth, the absolute number of new cases is still increasing. In 2007 there were an estimated 13.7 million chronic active cases, 9.3 million new cases, and 1.8 million deaths, mostly in developing countries. The disease was such a significant threat to public health, that when the British Medical Research Council was formed in 1913, its initial focus was tuberculosis research. It was not until 1946 with the development and marketing of streptomycin that effective treatment and cure became possible. However, the emergence of multidrug-resistant TB has again required the introduction of surgery as part of the treatment for TB infections.

On his arrival in the United States, Waksman worked for a few years on a family farm in New Jersey and then enrolled in Rutgers College in New Jersey. There he studied bacteria in culture samples from successive soil layers, among them the group of bacteria called actinomycetes. Graduating

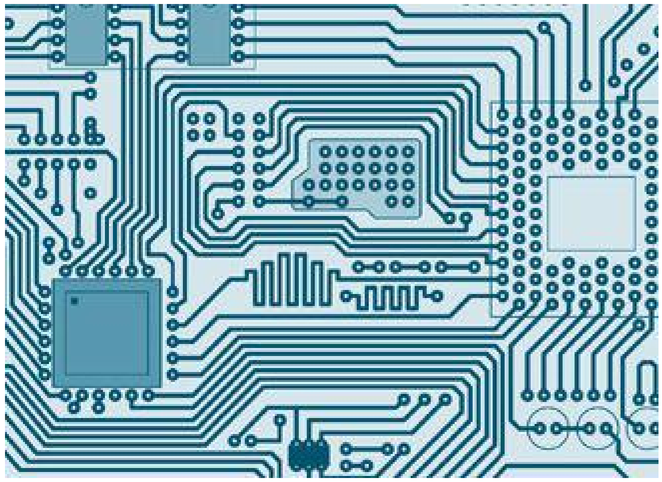
with a doctorate from University of California, Berkeley in 1918, aged 30, Waksman took a position at the Rutgers Bacteriology Department where he continued his research on soil microflora. Several years later, a young French microbiologist named René Dubos (1901–1982) joined his laboratory. By 1927 Dubos was studying the one-on-one effects of soil organisms in decomposing cellulose, and he took an approach that would lead to the development of modern antibiotics. In collaboration with Oswald Avery at the Rockefeller Institute Hospital, Dubos isolated a soil bacterium that could attack *Streptococcus pneumoniae*, which are the bacteria present in around 50 per cent of pneumonia cases. Pneumonia killed millions after the First World War. Dubos's discovery inspired Waksman to look for more pre-existing antibacterial organisms in soil samples. By 1940 Waksman and H. Boyd Woodruff had devised a technique for identifying natural substances with antibacterial properties. The screening was done by looking for growth inhibition zones around single colonies of systematically isolated soil microbes, grown under a variety of culture conditions, and then testing the inhibition on specifically targeted pathogenic bacteria.

With his students and associates, Waksman isolated new antibiotics, including *actinomycin* (1940), *clavacin, streptothricin* (1942), *streptomycin* (1943), *grisein* (1946), *neomycin* (1948), *fradicin, candicidin, candidin* and others. Two of these, streptomycin and neomycin, have found extensive application in the treatment of numerous infectious diseases of humans, animals and plants, and streptomycin has been listed as one of the ten patents that shaped the world. Waksman's donations of 80 per cent of the proceeds from licensing his patents funded the Waksman Institute of Microbiology at Rutgers University. Waksman's greatest honour came when he won the Nobel Prize in Physiology or Medicine in 1952, and he became popularly regarded as the 'father of antibiotics'.

'THE CAPTAIN OF THE MEN OF DEATH'

SIR WILLIAM OSLER appreciated the lethal danger of pneumonia, describing it as the '*captain of the men of death*' in 1918, as it had overtaken tuberculosis as one of the leading causes of mortality. He also described pneumonia as '*the old man's friend*' as death was often quick and painless, by comparison with other slower and more painful ways to die.

Pneumonia is still a common illness affecting approximately 450 million people a year, and occurring in all parts of the world. It is a major cause of death among all age groups and causes around four million deaths annually (7 per cent of the world's yearly total). Rates are greatest in children less than five, and adults older than 75 years of age, and it occurs about five times more frequently in the developing world compared to the developed world. Viral pneumonia (as opposed to bacterial pneumonia) accounts for about 200 million cases. It is the leading cause of death among children in low income countries, and the WHO estimates that around half of these deaths are theoretically preventable, as they are caused by the bacteria for which an effective vaccine is available.



CHAPTER 8

THE DIGITAL WORLD

IBM HARVARD MARK I COMPUTER

—— 1944 ——

HOWARD HATHAWAY AIKEN 1900–1973 AND REAR-ADMIRAL GRACE MURRAY HOPPER 1906–1992, UNITED STATES

These colleagues were pioneers at the beginning of the era of the modern computer and innovated computer programming. In 1939 development of an electro-mechanical computer began at IBM's Endicott laboratories in New York, under the direction of Harvard mathematician Howard Aiken. Dr Aiken was the conceptual designer of what was to become the IBM Harvard Mark I computer. Aiken envisioned a computing device that could solve difficult differential equations, and his computer was originally called the *Automatic Sequence Controlled Calculator* (ASCC). His design was influenced by Charles Babbage's Difference and Analytical Engines, and used decimal arithmetic and storage wheels and rotary switches in addition to electromagnetic relays. Aiken was assisted by Grace Hopper. The IBM machine weighed nearly 5 tons (5080 kg), was built from tens of thousands of switches, relays, clutches and rotating shafts driven by an electric motor. It measured 51 × 8 × 2 feet (15.5 × 2.5 × 0.6 m), and its 500 miles (800 km) of wire had three million connections. The Mark I was programmed by punched paper tape. It was used by the US Navy Bureau of Ships for performing repetitive calculations for the production of mathematical tables, and this marked the real dawn of the computer age. Punched card machines were the predecessors of stored-program computers. Basically a huge calculator, Aiken continually developed it as new electronic components became available, with his Mark IV computer having a magnetic core memory.

Hopper had been one of the Mark I's first programmers, and she developed the first *compiler* for a computer programming language. Hopper believed that programs should be written in a language close to English, rather than in *machine code* or similar languages. She understood that user-friendly languages would transform the computing industry. Her pioneering 1958 invention of *Flow-Matic* business language led to the development of *COBOL*, an acronym for Common Business-Oriented Language, which became the most ubiquitous business language of its day. Its primary domain is in business, finance and administrative systems for companies and governments. Hopper next developed validation software for the COBOL language and its compiler, as part of a COBOL standardization program for the entire Navy. Hopper is commonly referred to as 'the mother of COBOL language'. She also pioneered the implementation of standards for the programming language *FORTRAN*. Admiral Hopper's work over four decades included programming languages, software development concepts, compiler verification and data processing. Her early realization of the potential for commercial applications of computers, and her leadership in making her vision a reality, paved the way for modern data processing. She even coined the term 'bug' for a computer malfunction. This happened when a large moth had to be removed from the Harvard Mark I experimental computer in August 1945, '…*from then on, when anything went wrong with a computer, we said it had bugs in it*' (Grace Hopper quoted in *Time* magazine 16 April 1984).

MICROWAVE OVEN

—— 1945 ——

PERCY LEBARON SPENCER 1894–1970, UNITED STATES

The development of the microwave transformed the food industry in restaurants, supermarkets, commercial organizations and domestic homes. Spencer was in charge of the powertube division of the Raytheon Company when the Second World War broke out. He won for Raytheon the contract to produce working models of combat radar equipment, this having the highest military priority after the Manhattan Project. During the Battle of Britain the United States had received a model of a microwave (high frequency) magnetron from the British. The magnetron is the power tube at the heart of a radar set, used to generate microwave signals and detect enemy aircraft. However, magnetrons could not be mass-produced as the tube had to be machined out of solid copper, with tolerances of less than ten-thousandths of an inch. It took a skilled machinist a week to finish just one, but thousands were needed to help the RAF battle against the Luftwaffe. In 1941 magnetrons were only being produced at the rate of 17 a day, but by the time the USA entered the war in December, Spencer had invented a simpler magnetron that could be produced at a rate of 100 units a day. He then devised a method for semi-skilled workers to make the magnetrons on a purpose-designed conveyor belt, and production rose to 2600 a day by the end of the war.

MICROWAVES IN THE HOME

THE FIRST domestic microwave oven came on the market in 1955. It cost almost $1300 and was too bulky to fit in the average kitchen. Thanks to the development in Japan of a smaller magnetron, the first compact and practical domestic microwave oven was introduced in 1967 and cost $495. Today, there are over 200 million in use throughout the world, costing from as little as £39 each.

In 1945, while he was standing in front of an operating magnetron, a chocolate bar in Spencer's pocket melted. Intrigued, he placed popcorn kernels near the magnetron, and soon popcorn was popping out onto the laboratory floor. Spencer then put a raw egg in a pot in front of the magnetron. The egg exploded, splattering a nearby co-worker. Spencer realized that that microwaves could cook food quickly and unconventionally, by using high frequency electromagnetic waves. He continued to experiment with the magnetron and eventually he boxed it in and marketed it as a new way to cook food. The initial version of his new *microwave oven* was 6 feet (1.8 m) tall, weighed around 750 pounds (340 kg) and had to be cooled with water. The first generations of microwave ovens were used exclusively in restaurants, and on railway cars and ocean liners, places where large quantities of food had to be cooked quickly.

COMPUTER ARCHITECTURE

—— 1945 ——

JOHN VON NEUMANN 1903–1957, HUNGARY AND UNITED STATES

Stored-program computers were the major advance over the program-controlled computers of the 1940s. The genius behind them, John von Neumann (born János Neumann), possibly made more contributions to 20th-century science than any other man. Von Neumann was a Hungarian who emigrated to America. He was a child prodigy, and developed into one of the greatest mathematicians in history. His initial advances in *set theory* saw him then involved in all branches of mathematics, and he influenced quantum theory, 'universal constructor' theory, mathematical logic, cellular automata theory, economics, econometrics, strategy, operator theory, hydrodynamics, statistics, continuous geometry, functional analysis, numerical analysis, ergodic theory, computing theory and practice, and even defence planning.

His first book, in 1932, was on quantum mechanics, and in 1933 he was working alongside Einstein at Princeton University. Until 1940 he concentrated on pure mathematics, making a number of important theoretical contributions in physics. During and after the war, he became one of the greatest applied mathematicians. Von Neumann's principal contribution to the atomic bomb was in the concept and design of the

explosive lenses needed to compress the plutonium core of the *Trinity* test device that led to the Fat Man bomb that was dropped on the Japanese city of Nagasaki in 1945. When some the best scientists in the world were at Los Alamos trying to decide how to bring atomic fuel together quickly enough to create an explosion (the *A bomb*), he gave them the workable answer, *implosion*. Against opposition, he argued for the implosion concept against colleagues who felt such a design to be unworkable. Von Neumann also determined that the effectiveness of an atomic bomb would be enhanced with detonation some miles above the target, rather than at ground level.

With Edward Teller and Stan Ulam, von Neumann had worked out the key steps in the nuclear physics needed for thermonuclear explosions and the hydrogen bomb. Also with Ulam, he developed the *Monte Carlo technique*, computational algorithms that are commonly used to simulate complex situations in science and business. He also pioneered the area of game theory, one of the major scientific contributions of the first half of the 20th century, with his 1944 book *Theory of Games and Economic Behavior*. Towards the end of the war, von Neumann became involved with the development of computing machines and made several fundamental contributions. It was his idea to store the program (the sequence of instructions) in the machine as simply another form of electronic data. Until then, in order to reprogram a computer a person had to physically rewire it. His type of computer performed its operations sequentially, as opposed to recent computers which can perform several operations at once using ‘parallel processing’.

NEUMANN’S SELF-EVALUATION

VON NEUMANN submitted a short list of facts about his life to the National Academy of Sciences, stating: ‘*The part of my work I consider most essential is that on quantum mechanics, which developed in Göttingen in 1926, and subsequently in Berlin in 1927–1929. Also, my work on various forms of operator theory, Berlin 1930 and Princeton 1935–1939; on the ergodic theorem, Princeton, 1931–1932.*’ He thus makes little of his extraordinary contributions to computers, game theory and nuclear power.

Some of the developers of ENIAC program-controlled computer, recognizing its flaws, had moved towards ‘stored program architecture’. It was first formally described by von Neumann in the paper *First Draft of a Report on the EDVAC*, distributed in 1945. A number of projects to develop computers based on the stored-program architecture commenced around this time, and EDVAC (Electronic Discrete Variable Automatic Computer) was completed but did not see full-time use for an another two years. Nearly all modern computers implement some form of the stored-program architecture, making it the single trait by which the word ‘computer’ is now defined. Based upon Turing’s theoretical *universal computing machine*, von Neumann defined an architecture which uses the same memory to store both programs and data. His computer architecture is a design model for a *stored-program digital computer* which uses a *CPU* (central processing unit) and a single separate storage structure (which we know as *memory*) to hold both instructions and data. Such computers are theoretically equivalent to a Turing machine and have a sequential architecture. Virtually all contemporary computers use this architecture (or some variant of it). A ‘stored-program digital computer’ is a term often used interchangeably with *von Neumann architecture* and implies one that keeps its data and programmed instructions in a read-write *RAM* (random access memory). As director of the Electronic Computer Project at Princeton’s Institute for Advanced Study (1945–55), von Neumann helped to develop MANIAC (Mathematical Analyzer, Numerical Integrator and Computer) in 1952, which at the time was the fastest computer of its kind. MANIAC ran thousands of vacuum tubes, and is a precursor of today’s computers. However, because of advances in electronics, the mechanisms for transferring the data and instructions between the CPU and memory are considerably more complex than the original von Neumann architecture.

KIDNEY DIALYSIS MACHINE

—— 1945 ——

WILLEM JOHAN KOLFF 1911–2009, HOLLAND AND UNITED STATES

Millions of people owe their lives to Willem Kolff’s dialysis machine. Kolff suffered from dyslexia, a condition not recognized at the time, but he proceeded to study medicine at the University of Leiden in the Netherlands

and made his first invention, a device that helped patients with poor circulation by intermittently inflating and deflating a cuff fitted round the leg. On the day of the German invasion of the Netherlands in 1940, Kolff was in The Hague attending a funeral. Seeing German bombers pass overhead, he left the funeral and went straight to the city's main hospital, where casualties were already pouring in, and asked if they would like him to set up a blood bank. Provided with a car and an armed escort, he drove through the city's streets, dodging sniper bullets, and bought bottles, tubes, needles, citrate and other paraphernalia. Four days later, he had developed a store of supplies of blood, blood plasma and concentrated red blood cells, in effect the first blood bank in Europe. A month after the invasion, Kolff's mentor, the Jewish hospital director at Groningen, committed suicide and a Nazi was appointed in his place. Not wishing to work with this man, Kolff applied for a post in a small hospital in the town of Kampen, where he remained for the rest of the war, secretly helping the Dutch resistance movement.

In 1938 Kolff had been greatly affected by the death of a young man from kidney failure, Kolff said: '*I realised that removing 22 cubic centimetres of toxicity from his blood would have saved his life…I had to do something.*' Kolff devoted himself to research, and although Holland was now under German occupation, he succeeded in developing a prototype dialysis machine. He borrowed materials from a local factory, salvaged a water pump from an old Ford car, took used metal pieces from a downed German fighter plane and even used empty orange juice cans. In 1943 he made his first machine out of cellophane sausage skins wrapped around a cylinder, resting in an enamel bath of cleansing fluid. The patient's blood would be drawn through the tubing, into a revolving drum containing fluid to clean deadly impurities from the blood, and passed back into the body. At first, his experimental treatments on patients failed to work well, and 16 succumbed to renal illness. Then, in 1945, he successfully treated a female Nazi collaborator who was suffering from acute kidney failure (see box on page 319). Kolff's artificial kidney dialysis machine has been continuously improved, so that there are now an estimated 55,000 people in the United States with end-stage renal disease who are being kept alive by his invention. In 1950 Kolff moved to the United States and headed a team which invented and tested an artificial heart. However, Kolff never patented his original artificial kidney dialysis machine.

THE FIRST SUCCESSFUL KIDNEY DIALYSIS PATIENT

IN AUGUST 1945 Kolff was asked to treat Maria Schafstad, a 65-year-old woman who had been imprisoned as a Nazi collaborator, and who was in a coma due to renal failure. Although he realized that many of his fellow countrymen '*would have liked to wring her neck*', he accepted his duty as a doctor. After many hours of treatment, he recalled, '*she slowly opened her eyes and said, "I'm going to divorce my husband".*' Kolff concluded ruefully '*It's now been proven that the artificial kidney can save a life…But it's not been proven that it's of any real use to society.*' Treatment took a week but the woman survived for another seven years, before dying of an illness unrelated to her kidneys.

AK-47 ASSAULT RIFLE

—— 1947 ——

MIKHAIL TIMOFEYEVICH KALASHNIKOV B.1919, RUSSIA

This assault rifle has been called '*the most effective killing machine in human history*'. The gun is extremely reliable, cheap to make, relatively compact and easy to maintain and operate. It was designed for ease of use and repair by glove-wearing Russian soldiers in Arctic conditions, and its average service life can be up to 40 years. Kalashnikov designed it after first-hand experience of poor quality weapons during the Second World War. Its large gas piston, generous clearances between moving parts, and tapered cartridge case design allow the gun to operate despite the presence of large amounts of foreign matter and dirt. Kalashnikov has said '*I am proud of my invention, but I am sad that it is used by terrorists…When I see bin Laden with his AK-47, I get nervous. But what can I do? Terrorists are not fools. They too choose the most reliable guns.*' It was developed too late to see service in the Second World War, but showed its effectiveness in the Budapest 1956 uprising during which 7000 Russian troops and 50,000 Hungarians died. Since then it has become almost ubiquitous in the hands of fighters, still killing as many as a quarter of a million people every year across the world. The gun combines the mid-range capabilities of a rifle with the power of a machine gun, and can be easily handled by fighters as

young as 12 years old who feature in the various African and Asian warring regions.

Globally, the *AK-47* and its variants are the most commonly smuggled small arms, and are used by terrorists, guerrillas, criminals and governments alike. A World Bank estimate records that out of the 500 million total firearms available worldwide, 100 million are Kalashnikovs, of which 75 million are AK-47s. More AK-type rifles have been produced than all other assault rifles combined. One of the reasons for its popularity is that its price is falling in real terms, helping its spread across the world. A brand new Kalashnikov from a Russian factory costs around £145 ($240), depending on the derivative and size of the purchase. However, in Africa an AK-47 can be bought for around £18 ($30) in areas where supplies are plentiful. Kalashnikovs made in Jordan were bought by the US for the new Iraqi security forces for around £36 ($60) each, and stockpiled Balkan AK-47 variants only cost private US and European buyers £30 ($50) per rifle. After the Soviet retreat from Afghanistan, vast stockpiles of Kalashnikovs were taken by the Taliban and al Qaeda. Counterfeit, but effective, copies are made across the world, notably in Pakistan.

THE VIETNAMESE EXPERIENCE

'*ONE OF the bulldozers uncovered the decomposing body of an enemy soldier, complete with AK47. I happened to be standing right there, looking down into the hole and pulled the AK out of the bog. "Watch this, guys", I said, "and I'll show you how a real infantry weapon works." I pulled the bolt back and fired 30 rounds – the AK could have been cleaned that day rather than buried in glug for a year or so. That was the kind of weapon our soldiers needed, not the confidence-sapping M-16.*' David Hackworth, US Army battalion commander, recounting his Vietnam War experiences, *About Face*, 1989

TRANSISTOR

—— 1947 ——

JOHN BARDEEN 1908–1991, WALTER HOUSER BRATTAIN 1902–1987, WILLIAM BRADFORD SHOCKLEY 1910–1989, UNITED STATES

The transistor is the fundamental building block of circuitry in computers, mobile phones and practically every other electronic device. Barely the size of a fingernail, transistors were invented at AT&T’s Bell Telephone Laboratories in 1947. While there is some dispute about the actual inventor, the transistor which revolutionized technology had its genesis when Bardeen and Brattain applied electric contacts to a germanium crystal. The output power was larger than the input, and this phenomenon came to be called *current gain*. Their solid-state physics group leader Shockley saw the potential and worked on semiconductors, producing operational versions of the new device, a transfer resistor, which became known as a *transistor*. A former Bell employee built the first silicon transistor at Texas Instruments in 1954, and the first metal oxide semiconductor (*MOS*) transistor was developed by Bell in 1960. Transistors amplify current, for example they can be used to amplify the small output current from a logic integrated circuit so that it can operate a lamp, relay or other high current device. In many circuits a resistor is used to convert the changing current to a changing voltage, so the transistor is being used to amplify voltage. A transistor may be used as a switch (either fully on with maximum current, or fully off with no current) and as an amplifier (always partly on).

Transistors took over from the much larger vacuum tubes (valves), which tended to become hot. Early TV cabinets were made of wood as it was more resistant to the heat generated by valves, and early plastics tended to melt. Valves, relays and other electromechanical devices were quickly replaced by the much smaller transistor and then by the integrated circuit. However, early power transistors tended to need metal ‘heat sinks’ to dissipate their heat. They are now used in modern clocked analog circuits, voltage regulators, amplifiers, power transmitters, motor drivers and switches. Mass production has driven down the costs of this key active component of all modern electronics. Over a billion individual (discrete) transistors are now annually manufactured, but the vast majority are incorporated into

integrated circuits known as *microchips* or microprocessors, along with diodes, resistors, capacitors etc. to make complete electronic circuits. A single advanced microprocessor can use three billion transistors. Because of lower possible operating voltages, transistors are suitable for small, battery-powered applications, enabling the invention of the Walkman, laptop computers etc. Their small size, reliability, miniscule weight, economy and efficiency has revolutionized the modern world.

JOHN BARDEEN'S TWO NOBEL PRIZES IN PHYSICS

THE INVENTION of the transistor made the vacuum tube obsolete, and enabled the electronics revolution to accelerate. John Bardeen won the Nobel Prize in Physics in 1956 with Walter Brattain and William Shockley, as co-inventors of the transistor. Bardeen once told a reporter that '*I knew the transistor was important, but I never foresaw the revolution in electronics it would bring.*' However, it was the development of the theory of low-temperature superconductivity of which Bardeen was most proud. With Leon Cooper and John Schreiffer he proposed and developed the Bardeen, Cooper, Schreiffer (BCS) theory of superconductivity. He observed that the temperature at which a metal becomes superconducting is inversely proportional to its atomic mass. '*Superconductivity was more difficult to solve and it required some radically new concepts*', Bardeen said after the announcement of his second Nobel Prize. Superconductivity, in which electricity travels while experiencing little or no resistance, helped researchers to develop vital medical diagnostic tools as magnetic resonance scanning and imaging, and made possible the development of high-speed computers.

ZEBRA CROSSING

—— 1949 ——

GEORGE CHARLESWORTH 1917–2011, ENGLAND

These striped crossings were a universal improvement in pedestrian safety, as road traffic has increased exponentially since the invention of the car. This little known physicist and engineer was working at the Road Research Laboratory when he contributed to the team that produced Barnes

Wallis's *bouncing bomb* that was used to demolish German dams during the Second World War. The operation deprived the German Ruhr region of electricity for weeks, and badly damaged German morale. After the war, Charlesworth headed the team which decided on the black-and-white markings for pedestrian crossings, and he pushed through the pilot schemes which led to the markings being adopted universally throughout the world. After isolated experiments, the painted crossing was first used at 1000 sites in the UK in 1949 in its original form of alternating strips of blue and yellow. In 1951 they were implemented nationwide, but now in distinctive black and white stripes to enhance their visibility at night, becoming known as *zebra crossings* because of their colours. Charlesworth earned the nickname *Dr Zebra*.

THE BELISHA BEACON

BEFORE THE adoption of zebra stripes, pedestrian markings were simply marked with rows of metal studs, until amber-coloured globe lamps on black and white poles were used to distinguish them in 1934. They were named after the minister of transport at the time, Leslie Hore-Belisha (1893–1957). Constantly flashing Belisha beacons provide additional visibility to pedestrian crossings for motorists, primarily at night.

NICOTINE TOXICITY

—— 1950 ——

WILLIAM RICHARD SHABOE DOLL 1912–2005, ENGLAND

This noted scientist has saved millions of lives by discovering the links between smoking, asbestos and cancer. After research throughout the late 1940s, Doll, one of the world's most renowned epidemiologists, warned that smoking was a major cause of lung cancer. With Sir Austin Bradford Hill, Doll studied lung cancer patients in 20 London hospitals, trying to establish a link that connected the condition with exposure to motor vehicle fumes or the new road material tarmac. Instead, through his research he found that smoking was the common causative link. Doll himself gave up smoking two-thirds of the way through the study. Doll's report noted that: '…*the risk of developing the disease increases in proportion to the amount*

smoked. It may be 50 times as great among those who smoke 25 or more cigarettes a day as among non-smokers.' He also showed that cigarettes led to heart disease and other illnesses. In 1954, a huge study confirmed his findings, after which the British government issued advice that smoking and lung cancer were related. British people began to heed his advice – in 1954, 80 per cent of British adults smoked, today only a quarter do so. However, in the United States, the picture was different. Wilhelm Heuper of its National Cancer Institute stated publicly in 1954: '*If excessive smoking actually plays a role in the production of lung cancer, it seems to be a minor one.*' Because of the influence of the tobacco giants and their political lobbying, America was far slower than Britain or France to publicize the dangers of tobacco. Doll also pioneered work on the relationships between radiation and leukaemia, and between asbestos and lung cancer (1955).

THE DOLL PLAQUE

A PLAQUE in the Richard Doll Building in Oxford records Doll's words: '*Death in old age is inevitable, but death before old age is not. In previous centuries 70 years used to be regarded as humanity's allotted span of life, and only about one in five lived to such an age. Nowadays, however, for non-smokers in Western countries, the situation is reversed: only about one in five will die before 70, and the non-smoker death rates are still decreasing, offering the promise, at least in developed countries, of a world where death before 70 is uncommon. For this promise to be properly realised, ways must be found to limit the vast damage that is now being done by tobacco and to bring home, not only to the many millions of people in developed countries but also the far larger populations elsewhere, the extent to which those who continue to smoke are shortening their expectation of life by so doing.*'

CREDIT CARD

—— 1950 ——

FRANCIS (FRANK) XAVIER MCNAMARA 1917–1957 AND RALPH EDWARD SCHNEIDER 1909–1964, UNITED STATES

The invention of ‘plastic’ money has transformed financial transactions, simplified shopping and booking, and enabled Internet commerce. This small plastic card is issued to users as a system of payment, allowing its holder to buy goods and services based on the holder’s promise to pay for these goods and services. The issuer of the card creates a *revolving account*, and grants a line of credit to the user, from which the user can borrow money for payment to a seller, or as a cash advance to the seller. A credit card is different from a *charge card*, which requires the balance to be paid in full each month. Instead, credit cards allow the consumer a continuing balance of debt, subject to interest being charged. Before the advent of *plastic cards* (and cash machines) consumers were forced to queue at banks to get cash. Today there are 66 million credit cards in circulation in the UK, six million more than there are people and outstanding credit stands at about £60bn. (Thus each card is averaging out at owing around £1000.)

The modern credit card was the successor of a variety of merchant credit schemes. It was first used in the 1920s in the United States to sell fuel to the growing number of car owners. In 1936 American Airlines and the Air Transport Association had simplified the process with the *Air Travel Card*. They created a numbering scheme that identified the issuer of card as well as the customer account. With an Air Travel Card passengers could ‘*buy now, pay later*’ for a ticket against their credit, and receive a 15 per cent discount at any accepting airlines. In 1938 several companies started to accept each other’s cards and by the 1940s all the major US domestic airlines offered Air Travel Cards that could be used on 17 different airlines.

The concept of customers paying different merchants using the same card was expanded in 1950 by the founders of *Diners Club*, to consolidate multiple cards. Diners Club, which was created partially through a merger with *Dine and Sign*, produced the first ‘general purpose’ charge card, and required the entire bill to be paid with each statement. In 1949 salesman Frank McNamara had dinner at Major’s Cabin Grill, New York. The story goes that he then realized that he had left his wallet in his other suit. His wife rescued him by paying, but McNamara resolved never to face this embarrassment again. However, this may be an apocryphal story made up by the company’s publicist. In February 1950 McNamara and his lawyer partner Ralph Schneider returned to Major’s Cabin Grill. When the bill came, McNamara presented a small cardboard card, a Diners Club card, and signed for the purchase. Initially 14 restaurants accepted Diners Club cards,

with 200 of McNamara's friends and business associates being part the first-ever charge card system. Demand took off and by the end of the first year membership had grown to 20,000 card members. In 1951–2 Diners Club experienced rapid growth, with acceptance expanding to all major US cities. The first rental car companies joined up as merchants, along with hotels and florists. In 1953–4 Diners Club went global, becoming the first internationally accepted charge card. Diners Club built up a client base of 17,000 restaurants, hotels, motels and speciality shops that would happily pay it a 7 per cent fee for the business of its 750,000 members.

Diners Club had no serious competition until American Express in 1958 entered the credit card business, enlisting the aid of its worldwide contacts to recruit members. Through banks, American Express mailed applications to 8,000,000 depositors, people who obviously had money to spend. Its president also sent personal letters to 22,000 corporation presidents. More than 300 'American Expressmen' started calling on company CEOs all round the United States to sell its credit card, at a charge of $6 per year for initial card, and $3 for other members of the same firm. American Express next created a worldwide credit card network. (However, these were initially charge cards, which only acquired credit card features after BankAmericard had demonstrated the feasibility of the concept.) Until 1958, no one had been able to create a working revolving credit financial instrument, issued by a third-party bank, that was generally accepted by a large number of merchants (as opposed to merchant-issued revolving cards accepted by only a few merchants). In September 1958 Bank of America launched the first successful recognizably modern credit card, the *BankAmericard*, which evolved into the *VISA* system. In 1966 a group of California banks established *Master Charge* to compete with BankAmericard. This later evolved into *MasterCard*. It is difficult to imagine modern life without the presence of our ubiquitous credit cards.

THE FIRST MENTION

THE AMERICAN author Edward Bellamy (1850–1898) used the term *credit card* for purchases 11 times in his utopian novel *Looking Backward: 2000–1887* (1888). The philosopher and social commentator Erich Fromm called this forgotten work '*one of the most remarkable books ever published in America*' and it was the third biggest bestseller of its day, after *Uncle Tom's*

Cabin and *Ben Hur: A Tale of the Christ*. One sentence in the book should be studied by all investment bankers and those 'financial experts' involved in short-selling, arbitrage and hedge funds: '*…buying and selling is essentially anti-social in all its tendencies. It is an education in self-seeking at the expense of others, and no society whose citizens are trained in such a school can possibly rise above a very low grade of civilization.*'

POLIO VACCINATION

— 1952 —

JOHN FRANKLIN ENDERS 1897–1985, BOSTON, UNITED STATES

John Enders's work in polio and measles pioneered modern vaccination. Poliomyelitis was responsible for crippling hundreds of thousands of children each year. The breakthrough in its prevention was made in 1948 by a research group headed by John Enders at the Children's Hospital, Boston, Massachusetts. With his colleagues Frederick C. Robbins and Thomas H. Weller, he successfully cultivated in human tissue the human enterovirus known as *poliovirus*, the causative agent of poliomyelitis. This facilitated the development of a polio vaccine. The three scientists were awarded the Nobel Prize in Physiology or Medicine in 1954 '*for their discovery of the ability of poliomyelitis viruses to grow in cultures of various types of tissue*'. Their work was the first to show that viruses of this type could be grown and manipulated outside the body. In 1960 Enders led a team testing a measles vaccine, which was found to be completely effective. Enders's work was the cornerstone of modern vaccination research and development.

Their technique, the Enders-Weller-Robbins method, was used by the pioneering American researcher Jonas Salk (1914–1995), pictured right, to develop a polio vaccine in 1952. He publicly broadcast his success in 1953

on a radio show, giving no credit to his own team of researchers nor to the Nobel laureates. Salk's vaccine was used in the largest medical experiment in history, with 440,000 children receiving one or more injections, and 210,000 children having a placebo. A further 1.2 million children had neither a vaccine or placebo, so served as a control group. In 1955 it was announced that it had been 60–70 per cent effective against poliovirus type 1, 90 per cent effective against types 2 and 3, and 94 per cent effective against bulbar polio (affecting the bulbar region of the brain stem). There was now a programme of mass vaccination, and in the USA polio cases fell from 35,000 in 1953 to 5600 in 1957. Two polio vaccines are necessary for effective treatment, the first being Salk's injection of a deactivated (dead) poliovirus. The second vaccination treatment is an oral vaccine of an attenuated (crippled) poliovirus, with trials beginning in 1957. The oral vaccine was the brainchild of Albert Sabin (1906–1993), another American researcher. The combined vaccines reduced the estimated worldwide cases from 350,000 children in 1988 to 1652 in 2007. Salk had been backed by huge financial resources, spending a fortune to become the first to develop a vaccine. Because of his self-publicity, he was to a great extent scorned by the scientific community, especially Sabin, who called Salk '*strictly a kitchen chemist… He never had an original idea in his life.*'

FLOAT GLASS

—— 1953–1957 ——

LIONEL ALEXANDER BETHUNE 'ALASTAIR' PILKINGTON 1920–1995, ENGLAND

All high quality flat glass is now made by using Pilkington's *float glass* process. The first advances in automating glass manufacturing had been patented in 1848 by Henry Bessemer, whose system produced a continuous ribbon of flat glass by forming the ribbon between rollers. This was an expensive process, as the surfaces of the glass needed polishing. The larger sheets of 'plate glass' were made by casting a large puddle of glass onto an iron surface, and then polishing both sides, again a costly process. From the early 1920s, a continuous ribbon of plate glass was passed through a lengthy series of inline grinders and polishers, reducing glass losses and cost. Glass of lower quality, 'sheet glass', was made by drawing a thin sheet, held at the edges by rollers, upwards from a pool of molten glass. As

it cooled, the rising sheet stiffened and could then be cut. The two surfaces were not as smooth or uniform, and of considerably lower quality than those of float glass.

Plate glass windows are windows that are created by using a twin grinding and polishing process. Plate glass is characterized by the creation of larger sheets of glass but it also has become a term that is used for everyday window glass. For many years, inventors tried to achieve an improved and lower-cost process to replace the ‘plate glass’ method. Pilkington (not a relation of his company’s founders) and his associate Kenneth Bickerstaff made the breakthrough by creating a ribbon of ‘floating’ molten glass over a bath of molten tin, and manipulating it to achieve uniform thickness and a flat surface. The success of this process lay in the careful balance of the volume of glass fed onto the bath, where it was flattened by its own weight. The invention enabled Pilkington Glass to lead the world market for high quality flat glass for many years. From the early 1960s, the world’s leading flat glass manufacturers obtained licences to use the float glass process, and the twin grinding and polishing process became obsolete. The glass windows that are manufactured today are actually float glass windows, although we still call them sheet glass or plate glass windows. Float glass also allows for the inclusion of certain features and properties not possible in plate glass windows, such as added strength, noise insulation, thermal insulation, light-sensitivity and even self-cleaning. The float glass process is also known as the Pilkington process.

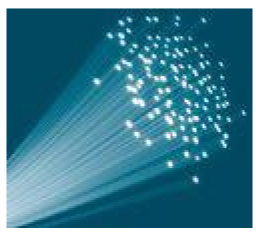
FIBRE OPTICS

—— 1954 ——

NARINDER SINGH KAPANY B.1926, INDIA AND UNITED STATES

This Indian-born American physicist is widely acknowledged as the father of fibre optics. Kapany’s body of work provided the basis for the developments of all later applications of fibre optics in communications and medicine. His research and inventions have encompassed fibre-optics communications, lasers, biomedical instrumentation, solar energy and pollution monitoring. He has over 100 patents. Kapany knew that a single beam of light could be transmitted along a glass tube, and hypothesized transmitting detailed images along the same path. He reasoned: ‘*Can we*

channel light through a curved path, even though we know that light travels in a straight line? Why is that important? Well, suppose you want to examine an internal organ of the human body for diagnostic or surgical purposes. You would need a flexible pipe carrying light. Similarly, if you want to communicate by using light signals, you cannot send light through the air for long distances; you need a flexible cable carrying light over such distances.' Kapany had first demonstrated successfully that light could be transmitted through bent glass fibres during his doctoral work at the Imperial College of Science in London, and published the findings in a paper in *Nature* in 1954. He developed applications of fibre optics for endoscopy at the University of Rochester in the 1950s and was the first to coin the term *fibre optics* in a 1960 article in the *Scientific American*. In 1956 he had designed a glass *gastroscope* which could be snaked down the throat for a detailed close-up view of the human stomach.



Fibre optics derives its name from the use of hair-thin strands of optical glass as light carriers. Light entering an ordinary clear glass or plastic rod is reflected over and over again from the inner surface until it emerges at the far end. This familiar principle causes the rod to act as a *light pipe*. Kapany had conceived of the idea of bunching thousands of microscopic glass rods, each of which would transmit a single point of light. The bundle of points of light should form an image in much the same way that the pattern of ink dots in a newspaper illustration forms a picture. With the aid of Bausch & Lomb technicians, Kapany made up several glass-fibre bundles, each of them containing up to a quarter of a million individual strands, a thousandth of an inch in diameter. As long as he kept the fibre's ends in the same relative position at each end of the bundle, he found that he could pass exact images through the flexible bundles even when they were tied in knots.

THE PRESS release issued by The Royal Swedish Academy of Sciences on the Nobel Prize in Physics for 2009 stated that one half of the prize had been awarded to the Chinese-born British and US citizen Charles Kao '*for groundbreaking achievements concerning the transmission of light in fibres for optical communication*'. (The other half went to Willard Boyle and George Smith for the invention of the CCD sensor.) Kao saw that the attenuation of a signal in optical fibres could be reduced by reducing impurities in the glass. In a 1966 paper he advanced the idea of using glass fibres for communication using light, and tirelessly evangelized the concept. Optical fibres now are responsible for telephone and computer communications worldwide, as copper wires could not cope with the incredible volume of electronic traffic that we have today. The Internet could not exist without fibre optics. Kapany's work was not acknowledged by the Nobel committee. In November 1999 *Fortune* magazine published profiles of seven people who have greatly influenced life in the 20th century but are 'unsung heroes'. Kapany was one of them.

Kapany said: '*…if we have a pipe whose insides are coated with a reflecting material, then photons or waves can be directed along easily without getting absorbed by the wall material…A light wave gets reflected millions of times inside such a pipe (the number depending on the length and diameter of the pipe and the narrowness of the light beam) … total internal reflection is a hundred per cent, which means that if we make a piece of glass as non-absorbent as possible, and if we use total internal reflection, we can carry a beam of light over long distances inside a strand of glass … This is the principle used in fibre optics.*' In 1960, with the invention of lasers, a new chapter opened in applied physics. From 1955 to 1965 Kapany was the lead author of dozens of papers on the subject. His writings spread the gospel of fibre optics, casting him as the pioneer in the field.

DISK DRIVES

—— 1955 ——

ALAN FIELD SHUGART 1930–2006, UNITED STATES

Shugart's career has defined the modern computer disk drive industry. Beginning as an IBM field service engineer repairing punch card accounting machines in 1951, Shugart was involved in every important development of the computer storage industry. Over that time computer storage systems shrank dramatically, and digital storage capacities rose exponentially. After transferring to an IBM research laboratory in 1955, Shugart helped to develop the first disk drive, named the Ramac, short for random access method of accounting and control. It was able to store five million characters of data. During his 18 years at IBM he managed the development of a number of products, including the IBM 1301, a 50-megabyte disk system that was the basis for Sabre, the nation's first online reservation system, which IBM created for American Airlines. Shugart rose to become the Direct Access Storage Product Manager, responsible for disk storage products, IBM's most profitable businesses at that time. Among the groups reporting to Shugart was the team that invented the *floppy disk*. A floppy disk is a disk storage medium composed of a disk of thin and flexible magnetic storage medium, and sealed in a rectangular plastic carrier lined with fabric that removes dust particles. They are read and written by a floppy disk drive (FDD). The earliest floppy disks, invented in the late 1960s, were 8 inches (20 cm) in diameter and became commercially available in 1971. For around 20 years, these disks were the only effective means to store and carry data between computers.

Shugart rose to become director of engineering for the systems development division, but left to join Memorex in 1969, eventually taking several hundred IBM engineers with him. In 1972 he left Memorex to found Shugart Associates in 1973, which introduced a lower-cost 8-inch (20-cm) floppy disk drive. In 1976 Shugart Associates introduced the first 5¼-inch (13.3-cm) floppy disk drive, selling for $390. By 1978 there were more than ten manufacturers producing such FDDs. The technology was intended for a new class of smaller computers that were being increasingly used outside

corporate data centres. Shugart's business partner Finis Conner remarked: '*It was a march to mobility, taking the computing power out of the computing room and putting it into the desktop*', and the two men realized that the cost of memory would drop dramatically with mass production. After being forced out of Shugart Associates, Shugart founded Seagate Technology with Conner and made the first Winchester 5¼-inch hard disks in 1979–80. At that time storage for personal computers was based on 5¼-inch floppy disks, and the two realized that a hard disk system of the same size but with a higher capacity would find a ready market. The company's first product stored five megabytes and sold for $1500. It became an instant success, driven by the exploding growth of companies like Apple Computer, its first customer, and others. Seagate became the world's largest independent manufacturer of disk drives and related components. By the end of the 1980s, these 5¼-inch disks had been superseded by the 3½-inch (8.9-cm) disks. They in turn have been superseded by data storage methods with much greater capacity, such as portable external hard disk drives, optical disks, memory cards, computer cloud networks and USB flash drives.

SHUGART AND POLITICS

SOMETHING OF a political maverick, in 1996 Shugart launched an unsuccessful campaign to elect Ernest, his Bernese mountain dog, to Congress. '*It would draw attention to the fact that the country is going to the dogs,*' Shugart said at the time. '*I want to alert the country that it's time to get more active in getting rid of all of the Republicans and Democrats.*' Shugart later wrote about his experience in a book, *Ernest Goes to Washington (Well, Not Exactly)*. He also backed a failed ballot initiative in 2000 to give California voters the option of choosing 'none of the above' in elections. With the dearth of politicians with any real business experience or sense of duty to voters, this option seems a sensible course of action for all democracies.

CONSUMER ELECTRONIC ENTERTAINMENT

—— 1955 *onwards* ——

AKIO MORITA 1921–1999 AND MASARU IBUKA 1908–1997, JAPAN

By a process of miniaturization and innovation, Sony has led the way in inventing and mass marketing consumer electronics. Beginning with the transistor radio (1955), Sony has given us the transistor television (1960), video cassette recorder (1975), Sony *Walkman* (1979), *PlayStation* game console (1994) and more, creating new genres of home entertainment. Ibuka was running a radio repair shop in Tokyo in 1945, while Morita was expected to enter the family's old-established brewing business. In 1946, however, they co-founded the Tokyo Telecommunications Engineering Corporation (renamed Sony in 1958), with just $375 in capital, and space in an abandoned department store which had been bombed during the war. The company's first product was a rice cooker. The company then built Japan's first magnetic tape recorder, but it was big and bulky, owing to restricted supplies after the war. Ibuka was instrumental in licensing new transistor technology from America's Bell Labs in the 1950s, making Sony one of the first companies to apply transistor technology to non-military uses. The Japanese economy was still in ruins, so the company set its sights on the American market with a brand new idea. In 1957 Sony released the world's first pocket transistor radio, immediately establishing a market leadership position for the company. Commenting on his decision to build the transistor radio, Morita said '*I knew we needed a weapon to break through to the US market, and it had to be something different. Something that nobody else was making.*'

From the outset, Morita's marketing concept was brand-name identification to communicate instantly high product quality. He always refused to manufacture under the names of other companies. *Made in Japan* was formerly a poor tagline for any product, but under Sony's leadership it became a selling point for consumer electronics, much as *Made in Germany* did for cars. Video innovation now became a priority for Sony engineers. Sony Corporation introduced the first 5-inch and 8-inch all-transistor televisions in 1960, foreshadowing Japan's future dominance of the television industry. By the time Sony's R&D team had finished its designs for the new TVs, it had created nine brand new transistor devices, including a high-frequency tuning transistor that was completed only a month before the sets were released. This author remembers valve televisions accommodated in large wooden cabinets to dissipate the heat. The advent of smaller, much cooler transistors on heat sinks, combined with new heat-resistant plastics, completely altered TV designs. Sony also wanted a high

quality colour television set, and in 1967 a new cathode-ray tube was perfected. The new colour television was named *Trinitron*, which since its introduction in 1968 set the standard for picture quality and design until the advent of digital and plasma televisions. Morita moved his family to America, and as a proponent of global localization, he familiarized himself with national economies and set up manufacturing plants all over the world. When Sony constructed a Trinitron colour television assembly plant in San Diego, California in 1972, it became the first Japanese-based consumer electronics manufacturing facility in the United States. Within a short time there were no American-owned manufacturers of televisions remaining.

In 1975 Sony released the first home video recorder, the *Betamax* system, a year before the rival Philips *VHS* system came out. Sony lost the battle for market dominance in this instance, but again it had been the first to create a new market. Another was the world's first portable music player. Morita noticed that his children and their friends played music from morning until night. He watched people listening to music in their cars and carrying large stereos to the beach and the park. Sony's engineering department was generally opposed to the concept of a tape player without a recording function (it would be added later), but Morita would not be denied. He insisted on a product that sounded like a high-quality car stereo yet was portable and allowed the user to listen while doing something else, thus the name *Walkman*. Eight out of ten Sony dealers were convinced that a cassette player without a recording mechanism had no real future. However, the product's compact size and excellent sound quality attracted consumers and kick-started the personal stereo revolution. Soon Walkmans, and equivalent music players released by other manufacturers, could be seen everywhere. People wore them when out running, going to work or lying on the beach.

The Sony *PlayStation* game console was launched in Japan in 1994 with only eight available titles, and then launched worldwide in 1995. Software companies were initially reluctant to support Sony's new format because Nintendo and Sega were already firmly established. However, with PlayStation and, most recently, *PlayStation2*, Sony has become the most successful games manufacturer ever. Other Sony innovations include the Compact Disc (CD) in 1982; the *Discman* in 1984; the first 8mm camcorder in 1985; the MiniDisc (MD) player in 1992; the Digital *Mavica* camera in 1997; Digital Versatile Disc (DVD) player in 1998; and the *Network Walkman* digital music player in 1999.

PROTEIN SEQUENCING

—— 1957 ——

FREDERICK SANGER B.1918, ENGLAND

Sanger completed his first degree in 1939 at Cambridge University. Because of his Quaker faith he was a conscientious objector during the war. However, he was allowed to continue researching for his doctorate. In the 1940s and 1950s new methods were being developed in biochemical separation and purification techniques, and it seemed that it might at last be possible to determine the chemical structure of protein molecules. Sanger developed methods to determine the order of the building blocks (amino acids) of the protein insulin. Sanger's principal conclusion was that the two polypeptide chains had precise amino acid sequences and, by extension, that every protein had a unique sequence. It was this achievement that earned him the Nobel Prize in Chemistry in 1958. His work led directly to DNA sequencing and a second Nobel Prize.

DOUBLE NOBEL PRIZE WINNERS

SANGER IS only the fourth person to win two Nobel Prizes, both being awarded in Chemistry – the first in 1958 and the second in 1980, an astonishing 32 years later. His 1980 prize was shared with Walter Gilbert and Paul Berg. The other double winners were Marie Sklodowska Curie, 1903 Physics and 1911 Chemistry; Linus Pauling, 1954 Chemistry and 1962 Peace; and John Bardeen, 1956 and 1972, both Physics.

INTEGRATED CIRCUIT (MICROCHIP)

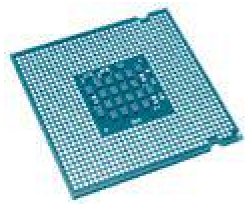
—— 1959 ——

GEOFFREY WILLIAM ARNOLD DUMMER 1909–2002, ENGLAND, JACK ST CLAIR KILBY 1923–2005 AND ROBERT NORTON NOYCE 1927–1990, UNITED STATES

This invention and its development completely changed our world and fuelled the personal computer revolution. An integrated circuit (IC) is an electronic circuit, manufactured by the patterned diffusion of trace elements into the surface of a thin substrate of semiconductor material. Additional materials are deposited and patterned to form interconnections between tiny semiconductor devices such as transistors, capacitators, resistors and diodes. They are used in virtually all electronic equipment today, allowing miniaturization of computers, phones and digital appliances, and a low cost of production. Geoffrey Dummer, a British electronics engineer, was the first to conceptualize the device, in the later 1940s. He believed that it would be possible to fabricate multiple circuit elements on and in a substance like silicon. In 1952 he presented his work at the US Electronic Components Symposium conference in Washington D.C., and in consequence has been called 'the prophet of the integrated circuit'.

Dummer finished his paper with the words: '*With the advent of the transistor and the work on semi-conductors generally, it now seems possible to envisage electronic equipment in a solid block with no connecting wires. The block may consist of layers of insulating, conducting, rectifying and amplifying materials, the electronic functions being connected directly by cutting out areas of the various layers.*' After the invention of ICs, he said: '*It seemed so logical to me; we had been working on smaller and smaller components, improving reliability as well as size reduction. I thought the only way we could ever attain our aim was in the form of a solid block. You then do away with all your contact problems, and you have a small circuit with high reliability. And that is why I went on with it. I shook the industry to the bone. I was trying to make them realise how important its invention would be for the future of microelectronics and the national economy.*' He had presented his ideas at many international symposia, but was short of funding and the lack of suitable manufacturing techniques to develop his idea. However, in 1957 at The International Components Symposium at Malvern, he presented a model to illustrate the

possibilities of solid-circuit techniques. The model represented a flip-flop in the form of a solid block of semiconductor material suitably doped and shaped to form four transistors. Four resistors were represented by silicon bridges, and other resistors and capacitors were deposited in film form directly onto the silicon block with intervening insulating films. The model was intended as a design exercise, but was not similar to the circuit patented by Jack Kilby two years later.



Kilby won the Nobel Prize in Physics in 2000 along with Robert Noyce in recognition of his part in developing the IC while working at Texas Instruments. A newly employed computer engineer, he did not yet have the right to a summer holiday, and so spent the summer working on circuit design. *The tyranny of numbers* was a huge problem in the 1950s – engineers were unable to increase the performance of their designs due to the huge number of components involved. In theory, every component needed to be wired to every other one, and they were typically placed in circuit boards and soldered by hand. In order to improve performance, more components would be needed, and it seemed that future designs would consist almost entirely of wiring. In summer 1958 Kilby came to Dummer's conclusion that manufacturing the circuit components en masse, in a single piece of semiconductor material, could provide a solution. He presented his findings to management, showing them a piece of germanium with an oscilloscope attached. Kilby pressed a switch, and the oscilloscope showed a continuous sine wave, proving that the integrated circuit could work. Now billions of transistors can be placed on tiny ICs. His US patent for *Miniaturized Electronic Circuits*, the first integrated circuit, was filed in early 1959. Kilby also is noted for patenting the electronic portable calculator and the thermal printer used in data terminals. Five months after Kilby's patent, Robert Noyce independently made a similar circuit, and he is credited with its co-invention. His patent was for a *Semiconductor Device and Lead Structure*. Noyce co-founded Fairchild Semiconductor in 1957 and Intel in 1968. Noyce was nicknamed 'the mayor of Silicon Valley' and

mentored many computer pioneers, including Steve Jobs, the founding father of Apple.

'THE TYRANNY OF NUMBERS'

THE TERM was first used by Jack Morton, vice president of Bell Labs in 1957, in a paper celebrating the tenth anniversary of the invention of the transistor. Referring to the problems many designers were having, he stated: '*For some time now, electronic man has known how "in principle" to extend greatly his visual, tactile, and mental abilities through the digital transmission and processing of all kinds of information. However, all these functions suffer from what has been called "the tyranny of numbers". Such systems, because of their complex digital nature, require hundreds, thousands, and sometimes tens of thousands of electron devices.*'

ORAL CONTRACEPTIVE PILL

— 1960 —

GREGORY GOODWIN PINCUS 1903–1967 AND MIN CHUEH (M.C.) CHANG 1908–1991, UNITED STATES

The *combined oral contraceptive pill* is often referred to as the *birth-control pill* or just *the pill*. It is a birth control method that includes a combination of the hormones oestrogen and progestogen. Taken by mouth every day, the pill inhibits female fertility by preventing ovulation. It is currently used by more than 100 million women worldwide. Pincus and Chang worked together studying hormonal biology and *in-vitro* fertilization at the Worcester Foundation for Experimental Biology in Shrewsbury, Massachusetts. In 1951, Pincus met Margaret Sanger, vice-president of the Planned Parenthood Federation of America, at a dinner party. She procured a small grant from PPFA for Pincus to begin hormonal contraceptive research. Pincus and Chang confirmed earlier research that progesterone would act as an inhibitor to ovulation, but needed more funding. In 1952 Sanger told her friend Katherine Dexter McCormick about the research. McCormick was a biologist and philanthropist who had inherited a substantial fortune from her late husband. She increased the funding to the levels necessary to develop the first birth control pill.

In order to prove the safety of ‘the pill’, human trials had to be conducted. These were initiated on infertility patients in Massachusetts using progesterone in 1953 and then three different progestins in 1954. However, trials of the pill as a contraceptive could not be carried out in Massachusetts, as dispensing contraception in that state was then a felony. In 1955 Puerto Rico was selected as a trial site, partially because there was an existing network of 67 birth control clinics advising low-income women on the island. Trials began in 1956, and some of the women experienced side effects from the pill, which was trademarked *Enovid*. The supervising physician wrote to Pincus reporting that Enovid ‘*gives one hundred percent protection against pregnancy* [but causes] *too many side reactions to be acceptable*’. Pincus and his collaborator, Harvard professor of gynaecology John Rock, disagreed, as their experience with patients in Massachusetts showed that placebos caused similar side effects. The trials were expanded to Haiti, Mexico and Los Angeles, with large numbers of women volunteering to try this new form of contraception. In May 1960 the Food and Drug Administration (FDA) approved Enovid for contraception. In 1961 the British Government announced that the pill was to be made available via the National Health Service. The contraceptive pill not only empowered women, but marked a turning point in medicine, as it was the first drug used by ‘healthy’ people to prevent something, rather than by the sick to treat an ailment. Since its invention, more than 300 million women are thought to have used the pill.

LASER TECHNOLOGY

—— 1960 ——

THEODORE HAROLD ‘TED’ MAIMAN 1927–2007, UNITED STATES

This first functioning laser (the acronym stands for light amplification by stimulated emission of radiation) has changed modern life in many ways. The *maser* (microwave amplification by stimulated emission of radiation), a device that produced coherent electromagnetic waves through amplification by stimulated emission, was invented independently in Russia in 1952 and the United States in 1953. Teams across the world began researching light amplification by stimulated emission of photons in 1958, following a research paper by Arthur Schawlow and Charles Townes which laid out a

theoretical basis for *laser* construction. Maiman's doctoral thesis had been in microwave-optical measurements of fine structure splittings in excited helium atoms. Working at Hughes Research Laboratories in Malibu, California, Maiman disagreed with other scientists who stated that a ruby was unsuitable as a laser, as it could not accept enough energy. He agreed with them that it would need an extraordinarily bright energy source, however. He then realized that the source did not have to shine continuously, which was what other teams were trying to achieve. Scouring manufacturers' catalogues, Maiman found a very bright lamp with a helical shape. He fitted a synthetic ruby crystal inside and on 16 May 1960 observed pulses of red light. It was the world's first laser. Maiman has since been called 'the father of the electrooptics industry', and additionally he held patents on masers, laser displays, optical scanning and laser modulation.

Other laser research teams were spurred in a different direction by Maiman's success. Within two weeks of the July 1960 press conference that announced Maiman's breakthrough, groups at Bell Labs and TRG had bought flash lamps like the one that had appeared in publicity photographs of Maiman. They reproduced his device and studied it in detail. The Bell team and another group independently made lasers out of a different type of ruby crystal. Another team had its calcium fluoride crystals re-cut into cylinders silvered at their ends, and achieved laser action from them in November 1960. The input power required was less than 1 per cent of that needed for Maiman's ruby laser. At Bell Labs, the team continued on its original path, and in December 1960 produced a continuous beam of infrared rays, the first gas laser. Altogether, by the end of 1960 three quite different types of laser had been demonstrated successfully.

USES OF LASERS

SURGERY: Lasers reduce the need for general anaesthesia, and are used in millions of medical procedures every year. The heat of the beam cauterizes tissue as it cuts, resulting in almost bloodless surgery and less infection. For example, detached retinas cause blindness in thousands of people each year. If detected early enough, a laser can ‘weld’ the retina back in place before permanent damage results. Optical fibres can also deliver laser beams with great precision inside the body to reduce the need for more invasive surgery.

INDUSTRY AND ENTERTAINMENT: One of the earliest uses of lasers was in surveying. To build the Channel Tunnel separate excavations were begun on both the English and French sides of the Channel. Laser surveying brought the two together with a misalignment of only a few inches over 15 miles (24 km). Supermarket checkout scanners, CDs, DVDs, laser holograms for security on credit cards, and laser printers are just some of the consumer products that rely on lasers. Industrial lasers cut, drill and weld materials ranging from paper and cloth to diamonds and hard alloys, far more efficiently and accurately than metal machine tools.

ADVANCING SCIENCE: Lasers were first used for scientific research in the fields of atomic physics and chemistry. However, uses were quickly found in other disciplines. Focused laser beams are used as ‘optical tweezers’ to manipulate biological samples such as red blood cells and micro-organisms. Five researchers have shared Nobel Prizes for using lasers to cool and trap atoms and to create a strange new state of matter (the *Bose Einstein condensate*) that probes the most fundamental physics. The development of lasers constantly allows researchers to make new discoveries, with unforeseeable uses to benefit mankind.

COMMUNICATIONS: In the 1980s telecommunication systems relied on bulky copper cable, which had reached the limits of its signal-carrying capacity and already filled the duct space under city streets with no room for expansion. Laser light beamed through a single strand of glass optical fibre, thinner than a human hair, can carry more than half a million telephone conversations, or thousands of computer connections and TV channels. The light reflects off the inner surface of the glass fibre as it travels along it. Without fibre optics the Internet could not exist.

DANGERS OF PESTICIDES

—— 1962 ——

RACHEL LOUISE CARSON 1907–1964, UNITED STATES

In 1936 Carson was appointed a junior aquatic biologist with the US Bureau of Fisheries, becoming one of only two women employed there at a professional level. Her first book, *Under the Sea-Wind*, (1941), showed her ability to present intricate scientific material in clear language. In 1943 she was promoted to the position of aquatic biologist in the newly created US Fish and Wildlife Service, where she authored many bulletins directed at the American public. One series, known as *Conservation in Action*, was devoted to explaining in laymen's language the wildlife and ecology of national wildlife refuges. In 1951 Carson's second book, *The Sea Around Us*, was published and translated into 32 languages. It was on *The New York Times*'s best-seller list for 81 weeks. Carson was the first advocate of environmental conservation. *The Sea Around Us*, along with *The Edge of the Sea*, a third book published in 1956, opened up a new perspective on environmentalism and the science of *ecology*, the study of *our living place*.

Carson's last book, *Silent Spring* (1962), awakened society to human responsibility for other forms of life. She documented, in minute biological detail, the true menace to the ecosystem caused by harmful pesticides. Carson had become interested in the danger of pesticides while still associated with the Fish and Wildlife Service. Her concern was accelerated with the introduction of the pesticide DDT (dichlorodiphenyltrichloroethane). Carson's marine studies had provided her with early documentation of the effects of DDT on marine life. Since abnormalities always show up first in fish and wildlife, biologists were the first to see the effects of impending danger to the overall environment. Carson had long been aware of the dangers of chemical pesticides, but was also conscious of the controversy her views would arouse within the

agricultural community, which needed such pesticides to increase crop production. Her book provoked personal attacks upon her professional integrity. The pesticide industry mounted a massive campaign to discredit Carson even though she did not urge the complete banning of pesticides. Instead she recommended that research should be conducted to ensure that pesticides were used safely, until alternatives to dangerous chemicals such as DDT were found. The US government, however, ordered a complete review of its pesticide policy, and Carson was asked to testify before a Congressional committee along with other witnesses. As a direct result of the study, DDT was banned in the US in 1972, and it was subsequently banned for agricultural use worldwide under the Stockholm Convention.

CARSON AND ENVIRONMENTALISM

WITH THE publication of *Silent Spring*, Carson is credited with launching the contemporary environmental movement, and awakening concern about the environment. In a television interview, Carson once stated that '*man's endeavors to control nature by his powers to alter and to destroy would inevitably evolve into a war against himself, a war he would lose unless he came to terms with nature.*' Her works have profoundly affected the world's attitude towards conserving the environment and ecology.

DISCOVERY OF STEM CELLS

—— 1963 ——

ERNEST ARMSTRONG MCCULLOCH 1926–2011 AND JAMES EDGAR TILL B.1931, CANADA

Stem cell therapy, which developed from their work, has the potential to dramatically change the treatment of human disease. McCulloch, a cellular biologist, and Till, a biophysicist, worked together at the Ontario Research Institute and at the University of Toronto. From 1957 McCulloch's research concentrated on blood formation and leukaemia. Together with his colleague, McCulloch created the first quantitative, clonal method to identify stem cells, and used this technique for pioneering studies. McCulloch's experience in haematology, combined with Till's experience in biophysics, enabled them to offer a very productive combination of

expertise. In the early 1960s McCulloch and Till started a series of experiments in which they injected bone marrow cells into irradiated mice. Small lumps occurred in the spleens of the mice, in proportion to the number of bone marrow cells injected. Till and McCulloch called the nodules ‘spleen colonies’, and speculated that each nodule arose from a single marrow cell: perhaps a ‘stem cell’. Stem cells have the capacity to regenerate tissue over a lifetime. They are self-renewing and have the potency to differentiate into different cell types.

POTENTIAL USES OF STEM CELLS

MEDICAL RESEARCHERS anticipate being able to use technologies derived from stem cell research to treat a wide variety of diseases including: treatment for stroke, traumatic brain injury, learning defects, Alzheimer’s disease, Parkinson’s disease, missing teeth, muscle damage, multiple sclerosis, wound healing, spinal cord injury, osteoarthritis, rheumatoid arthritis, Crohn’s disease, cancers in multiple sites, muscular dystrophy, baldness, diabetes, deafness and blindness.

Till and McCulloch were now joined by graduate student Andy Becker, and they demonstrated that each nodule in fact did arise from a single cell. They published their results in *Nature* in 1963. In the same year, in collaboration with Lou Siminovitch, a Canadian molecular biologist, they obtained evidence that these cells were capable of self-renewal, a crucial aspect of the functional definition of stem cells that they had formulated. The work of McCulloch and Till revolutionized cell biology and cancer therapy, with their discovery of stem cells in the haematopoietic blood cell system, and led to revolutionary therapy with bone marrow transplants to help leukaemia patients survive. A major focus of McCulloch’s research before his death was on cellular and molecular mechanisms affecting the growth of malignant blast stem cells obtained from the blood of patients with acute myeloblastic leukaemia. Considering that recent Nobel Prizes have been awarded to Obama, Gore, Kissinger, Friedman, Arafat et al., one wonders why on Earth McCulloch and Till have not been granted this recognition.

PACKET SWITCHING

— 1965 —

DONALD WATTS DAVIES 1924–2000, WALES

Donald Davies is remembered as '*the scientist who enabled computers to talk to each other and thus made possible the Internet*'. Davies started his career in a small team at the National Physics Laboratory in Teddington, under the scientific genius Alan Turing, the man who first conceptualized computer programming. Davies gave the name *packet* to a chunk of data. Davies said '*I thought it was important to have a new word for one of the short pieces of data which travelled separately. This would make it easier to talk about them. I hit upon the word packet in the sense of the small package.*' He also led a team that built one of the first functioning networks using packet data. He was reported in *The Guardian* in 1997 as saying that it was inefficient for a computer to send an entire file to another computer in an uninterrupted stream of data, '*chiefly because computer traffic is "bursty" with long periods of silence. So, in November 1965, I conceived the use of a purpose-designed network employing packet-switching in which the stream of bits is broken up into short messages, or "packets", that find their way individually to the destination, where they are reassembled into the original stream.*' Davies coined the term '*packet switching*' for the data transmission that is a fundamental element of the workings of the Internet.

The work of his team was presented at a 1967 conference in Tennessee where the Advanced Research Projects Agency (part of the US Department of Defense) presented a design for creating a computer network. This led to the Internet prototype, the ARPANET. Unfortunately, like most British breakthroughs, funding was not available for a wide area network experiment by Davies, but his scientific papers were used worldwide, especially in America by ARPA and others to develop the technology. Davies developed a UK version of the ARPANET, mainly laboratory-based. ARPA's designers used his self-routing method for messages as the transport mechanism of the ARPANET, and the ARPANET subsequently evolved into the Internet. Paul Baran at RAND Corporation had also been working on computer networks, and one of his parameters was the same as Davies's packet size of 1024 bits, which became the industry norm.

Davies later moved into data-security systems, working for teleprocessing systems, financial institutions and government agencies. He was among the first to realize that malicious interference had to be

prevented for the Internet and secure transactions to be able to succeed. He published several books upon communication networks, computer protocols and network security. *Communications Networks for Computers* (1973) was groundbreaking. Davies also pioneered work in the 1980s on Smart Cards, as he believed they would be useful components in the secure operation of financial services over open networks. Davies and his team at NPL managed to get substantial funding from the banks, EFTPOS (Electronic Funds Transfer at Point of Sale) providers, American Express, the Post Office, Texas Instruments and other companies. By the mid-1980s this TTCC (Tokens and Transactions Control Consortium) had moved quickly into delivering solutions, focusing on high-speed encryption and authentication of sender and recipient identities. Regulation of secure access to, and private communication across, an open network by authorized users was enabled by what we now call an *Intranet*. An early application of the PC encryption card was found in the EFTPOS terminals in supermarkets. Of course, supermarkets can now use this payment method to build up databases of customer needs and patterns of shopping, and also to directly input these retail purchases into databases to trigger their own stock fulfilment systems. Davies was a pioneers of ‘Smart Card’ development, whereby retailers receive information upon shoppers’ purchase patterns.

EMAIL (ELECTRONIC MAIL)

—— 1971 ——

RAYMOND SAMUEL TOMLINSON B.1941, UNITED STATES

Tomlinson accelerated and revolutionized business and personal communications with his innovation. While working for the technology company of Bolt, Beranek and Newman, Tomlinson helped to develop the TENEX operating system, including the Advanced Research Projects Agency Network (ARPANET) Network Control Protocol and Telnet implementations. He next wrote a file-transfer program called CPYNET to transfer files through the ARPANET. ARPANET was the world’s first operational packet-switching network, and the core network of a set that came to compose the global Internet.

The network was funded by the US Defense Advanced Research Projects Agency (DARPA), for use by its projects at universities and research laboratories in the USA. Tomlinson was asked to change a program called SNDMSG, which sent messages to other users of a time-sharing computer, to run on TENEX. In 1970 he updated it, so that it could copy messages (as files) over the network. Tomlinson then added code he took from CPYNET to SNDMSG so that, in 1971, messages could be sent to users on other computers on the ARPANET. This was the first significant demonstration of a cross-platform email system. When Tomlinson showed his email messaging system to one of his colleagues, Jerry Burchfiel, Burchfiel warned him: '*Don't tell anyone! This isn't what we're supposed to be working on.*'

Although email had been previously sent on other networks such as PLATO and AUTODIN, Tomlinson had devised a system to send mail between users on different hosts connected to the ARPANET. Previously, mail could be sent only to others who used the same computer. To achieve this, Tomlinson used the @ symbol to separate the user from their machine, which has been used in email addresses ever since. The first email (electronic mail) Tomlinson sent was a test message from one DEC-10 computer to an identical computer placed next to it. Tomlinson's work was quickly adopted across the ARPANET, which significantly increased the popularity of email, and the rise of the Internet increased its usage exponentially. By May 2009 there were about 1.9 billion email users worldwide. For 2014, the Radicati research group projects 2.5 billion email users worldwide.

CARDIAC PACEMAKER AND LITHIUM IODIDE CELL

—— 1960 *and* 1971 ——

WILSON GREATBATCH 1919–2011, UNITED STATES

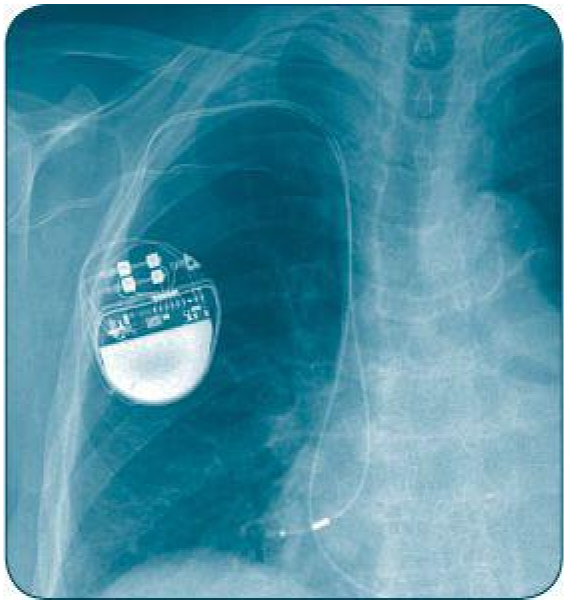
There are about three million people worldwide with pacemakers, and each year new 600,000 pacemakers are implanted. The Canadian John Hopps had created the first artificial pacemaker in 1950, but it was too large to be implanted in a body. Swedish doctors Rune Elmqvist and Åke Senning designed the first implantable pacemaker, but the device failed within hours in 1958. Derivatives of their first device are still being made, but Greatbatch's independent work led to faster development of the technology. During the Second World War, Wilson Greatbatch left his student teacher course to become a military radioman. After the war, the GI Bill gave him the opportunity to take an engineering degree at Cornell University, where the 26-year-old was distinguished for having the most children (five) of anyone in his class. Working part-time at Cornell's animal behaviour farm, Greatbatch talked with visiting brain surgeons during lunch breaks, and learned about 'complete heart block'. In this disease, the electric impulse sent by the heart's sinus node to the heart muscles, causing them to contract and pump blood, is disrupted. At the time, heart block was treated with a painful electric shock delivered via bulky external equipment. Greatbatch decided to design an artificial pacemaker that could be implanted in the chest and deliver milder shocks that would cause the heart to beat. However, in the early 1950s, no components small enough to build an implantable device were available.

Greatbatch's 'eureka moment' happened in 1958. Transistors had recently become available, and he began building an oscillator with one transistor to record heartbeat sounds. However, he incorporated the wrong transistor, which produced a pulse that mimicked the rhythm of a heart. He said '*I stared at the thing in disbelief, thinking this was exactly the properties of a pacemaker.*' In 1958, Greatbatch met Dr William Chardack of Buffalo's Veterans Administration Hospital and told him about the pacemaker idea. Chardack replied that Greatbatch could save 10,000 lives a year with such a device, which now could be made feasibly small because transistors were available. Within two weeks, Greatbatch had built a workable pacemaker in his shed. Greatbatch licensed his invention to Medtronic Inc., which received orders for 50 pacemakers at $375 each. In 1960 the 77-year-old Henry Hannafield became the first recipient of a Chardack-Greatbatch *implantable pulse generator*.

WHAT GREATBATCH DID NEXT

GREATBATCH WORKED on a biomass energy project, planting thousands of acres of poplar trees. This in turn aroused his interest in cloning plants and working with tissue culture and gene synthesis. His company, Greatbatch Gen-Aid, went on to attempt the synthesis of genes that can block retroviral diseases like AIDS and T-cell leukaemia. Greatbatch acquired three patents with scientist John Sanford in the 1980s and 1990s for methods of inhibiting the replication of AIDS and another similar virus in cats. Greatbatch preferred to describe himself as an engineering executive or entrepreneur rather than an inventor, but he held more than 220 patents.

In the 1970s, after more than ten years of successful pacemaker use, Greatbatch focused on improving battery design, as existing mercury batteries were unreliable and short-lived. In 1968 a Baltimore company patented a lithium battery cell with a high voltage and an energy density near the physical maximum. Unfortunately, it had a high internal impedance which limited its current load to under 0.1 mA and it was thus considered useless for any practical applications. Greatbatch decided to introduce this invention into the pacemaker industry, which could readily use a high impedance battery. A research team under Ralph Mead developed the WG1 cell, which Greatbatch promoted to pacemaker developers in 1971, but it was met with limited enthusiasm. However, the lithium-iodide cell manufactured by Greatbatch is now the standard corrosion-free cell for all pacemakers, having the energy density, low self-discharge, small size and reliability needed. Other types of lithium batteries were then developed across the world, and they are widely used in consumer electronic products.



PRODUCTION OF MONOCLONAL ANTIBODIES

—— 1975 ——

CÉSAR MILSTEIN 1927–2002, ARGENTINA AND ENGLAND, AND GEORGES JEAN FRANZ KÖHLER 1946–1995, GERMANY

Milstein was called the ‘father of modern immunology’, and opened up new fields for both diagnostic and therapeutic uses of antibodies, pioneering an enormous expansion in the exploitation of antibodies in science and medicine. This Anglo-Argentine immunologist worked at the National Institute of Microbiology, Buenos Aires, but following a military coup he resigned in 1963. Milstein returned to Cambridge University where he had studied for his doctorate, and joined the staff of the Medical Research Council Laboratory of Molecular Biology, serving as its deputy director from 1988 to 1995. In 1975, with Georges Köhler, he developed the hybridoma technique for producing monoclonal antibodies. These are pure, mass-produced antibodies that recognize only one antigen. The Milstein-Köhler method for monoclonal antibody production has since been adopted universally, and such antibodies are used in laboratory research, in medical diagnostics, and in medical treatments to neutralize bacterial toxins. In 1984, Milstein, with Köhler and Niels Kaj Jerne (1911–1994), shared the Nobel Prize in Physiology or Medicine. Jerne had developed a ‘network

theory’ to explain the interactive processes by which the human immune system creates antibodies against disease.

Research into antibodies essentially began in the 1890s with the discovery of serum therapy by Emil Adolf von Behring and Kitasato Shibasaburō. Serum from one individual who was recovering from a bacterial infection could be used to protect another from the effects of the bacterial toxins. From this beginning there developed a twin focus to research into antibodies: on both the structural basis of their diverse specificities and their exploitation for use in therapy. Milstein began to study antibody diversity at a time when almost nothing was known about its molecular and genetic basis. With Köhler, Milstein devised the hybridoma technique for fusing cancer cells with antibody-producing cells to produce homogeneous (monoclonal) antibodies. They focused on using monoclonal antibodies as *markers* to allow distinction between different cell types. Milstein also foresaw the potential wealth of ligand-binding reagents that could result from applying recombinant DNA technology to monoclonal antibodies, inspiring the development of the field of antibody engineering.

THE MARK OF A TRUE SCIENTIST

MILSTEIN ACTED as a guide and inspiration to many in the antibody field as well as devoting himself to assisting science and scientists in less developed countries. He carried on researching until the end of his life. Milstein did not patent his ground-breaking discovery since he believed that it was mankind’s intellectual property. His work was not pursued for any economic interest, but only for scientific ends.

APPLE COMPUTER PRODUCTS

—– 1976 *onwards* —–

STEVEN PAUL ‘STEVE’ JOBS 1955–2011 AND STEPHEN (STEVE) GARY ‘WOZ’ WOZNIAK B.1950, UNITED STATES

Probably no company has done more to advance invention and innovation in the last three decades than Apple Inc. Presently, Apple’s best-known hardware products are *Macintosh* computers, the *iPhone*, *iPod* music player and *iPad*. In software Apple offers the *Mac OS X* computer

operating system, the *iTunes* media browser, the *Safari* web browser and the *iLife* suite of multimedia and creativity software. Its user-friendly software innovations have broadened the spectrum of people using computers (see entry on Microsoft). *Fortune* magazine rated Apple as the world's most admired company in 2008, 2009 and 2010. As of May 2011, Apple is the third largest company in the world by value, after Exxon Mobil and Petrochina, and the most valuable technology company in the world, having overtaken Microsoft. In July 2011 Apple had larger financial reserves than the US government, \$76.4 billion, compared with the government's \$73.7 billion. Apple has always gone against the traditional notions of corporate culture, with a flat organizational hierarchy, free-wheeling idea generation and informal attire, and has engendered massive brand loyalty. In 1997 its then CEO, John Sculley, said '*People talk about technology, but Apple was a marketing company. It was the marketing company of the decade.*'

Apple was set up by Steve Jobs and Steve Wozniak in 1976 to market their *Apple I* personal computer, which was sold as an assembled circuit board (motherboard) with CPU and RAM but lacking a keyboard, monitor and case. They introduced the Apple II in 1977, the first PC to offer colour graphics, open architecture and a 5¼-inch (13.3-cm) floppy disk for storage rather than cassette tapes. With the computer was offered the *VisiCalc* spreadsheet program, which was widely adopted by business users. This helped with home sales, as office users became used to Apple software. *Apple II* was the first consumer PC to resemble the machines that have gone on to transform our lives. In 1979 Jobs saw the Xerox *Alto* computer and he admired the revolutionary mousedriven graphical user interface (GUI) that it used. He was convinced that all future computers would use a GUI. He had developed the Apple *Lisa* by 1983, the first personal computer sold to the public with a GUI, but it was a commercial failure because of its high

price and limited software. In 1984 the Apple *Macintosh* was launched, a breakthrough product for Apple, but it came with a high price and (again) limited software availability. However, the launch of Apple's *LaserWriter*, the first *PostScript* laser printer sold at a buyer-friendly price, and the early desktop-publishing package *PageMaker* increased sales dramatically. The Macintosh's advanced graphics, its GUI and PageMaker virtually created the desktop publishing phenomenon, and since this time Apple computers have dominated the publishing, design and advertising industries.

THE GREATEST BUSINESSMAN OF ALL TIME?

IN AUGUST 2011 Steve Jobs stepped down as CEO of Apple because of continuing health problems, while remaining as chairman. Shares fell five per cent overnight. Commentators around the world reflected that Jobs had a strong record of innovation and marketing expertise, and that his financial returns also made up the key strands of an exceptional business leader. However, he also initiated a strong business culture at Apple and strove for perfection, leaving a lasting legacy. In his second period at Apple, he turned the failing company around to become the most valuable company in the world at the time of his departure, with a market capitalization of $341.5 billion compared to Exxon's $334 billion. Apple shares rocketed 9000 per cent from the time of Jobs's return to lead Apple in 1996. Not content with transforming the consumer electronics, music and publishing markets, in his time away from Apple he acquired a small graphics division from Lucasfilm. He transformed it into *Pixar*, the animations studio that created *Toy Story* and *Finding Nemo*, selling it for $7.4 billion to Disney in 2008 and becoming a Disney director and its largest shareholder. Jobs's successor Tim Cook, who was paid $59 million (including a $52 million stock award) in 2010, has been handed a $384 million (£235 million) pay package as long as he stays at Apple until 2021. In October 2011, a few weeks after Jobs stepped down from Apple, he died after a seven-year battle with pancreatic cancer. Jobs was not just a superb businessman, but is listed as either primary inventor or co-inventor in 342 US patents or patent applications. These relate to a range of technologies from computer and portable devices to user interfaces (including touch-based), speakers, keyboards, power adapters, clasps, sleeves, lanyards and packages.

A Macintosh Portable computer was launched in 1989, but it was bulky and was replaced by the hugely popular *PowerBook* in 1991. Its modern ergonomic design, light weight and 12-hour battery life made it the first true laptop computer, as powerful as a desktop Macintosh. Successive Apple laptops have seen astonishing advances in design and capabilities. Lack of focus caused the company's fortunes to slip back for a period, and its expensive Apple II computer took sales from the Macintosh range, while Microsoft *Windows* became the all-conquering software. The *Newton* PDA (personal digital assistant) was not a real success, but helped Apple gain useful knowledge of small-scale electronic devices.

A boardroom battle had seen Jobs forced out of his beloved company in 1985, with Apple floundering in the marketplace in his absence. In 1996 Steve Jobs was lured back to lead the company, and from 1998 Apple returned to profitability, collaborating with Microsoft on some software projects. In 1998 the Jonathan Ive-designed *iMac* was launched. It had a unique eye-catching design, and sold 800,000 units in its first five months of sale. In 2001 the Ive-designed *iPod* was a phenomenal success, with over 100 million of the digital audio players being sold within six years. In 2003 Apple's *iTunes* store came online, offering music downloads and integration with the iPod. The *MacBook Pro* was Apple's first laptop with an Intel microprocessor, and it launched in 2006. In 2007 the *iPhone* was unveiled, and Jobs announced that the company was now focused on mobile electronic appliances, not just computers. In 2008 Apple became the third-largest mobile handset supplier in the world due to the popularity of the iPhone. The *iPad* media tablet appeared in 2010, using the same touch-based operating system as the iPhone. It shifted 500,000 units in its first week of sale. In 2011 Apple unveiled *iCloud*, its new online storage and syncing service for music, photos, files and software. In June 2011 Apple overtook Nokia to become the world's biggest smartphone maker by volume.

GLOBAL POSITIONING SYSTEM (GPS)

—— 1978 ——

IVAN ALEXANDER GETTING 1912–2003, BRADFORD PARKINSON B.1935 AND ROGER L. EASTON B.1921, UNITED STATES

Without the Global Positioning System (GPS), we would not have digital mobile phones, *satnavs* and a host of other modern inventions. Many scientists worked in the various research teams developing GPS, but three men in particular have received multiple awards for their work. Ivan Getting, a physicist and electrical engineer at MIT, established the basis for GPS, improving on the Second World War land-based radio system called *Loran* (Long-range Radio Aid to Navigation). He had been the co-leader of the research group which developed an automatic microwave tracking fire-control system, enabling anti-aircraft guns to destroy a significant percentage of the German *V-I* flying bombs which attacked London. Bradford Parkinson was a USAF colonel and a professor of aeronautics and astronautics at Stanford University, who conceived the present satellite-based system in the early 1960s, and developed it in conjunction with the US Air Force. Roger Easton is the principal inventor and designer of the GPS, and in 1955 he co-wrote the successful proposal for a US satellite programme, named *Project Vanguard*. Easton also invented the *Minitrack* tracking system to determine the Vanguard satellite's orbit. When the Soviet *Sputnik* satellite was launched in 1957, Easton extended the system to actively follow unknown orbiting satellites. Later in his career at the Naval Research Laboratory, Easton conceived, patented and led the development of essential enabling technologies for the United States Global Positioning System. During the 1960s and early 1970s Easton developed a time-based navigational system with passive ranging, circular orbits and space-borne high precision clocks placed in satellites.

THE WONDER OF MINIATURIZATION

GPS SIGNALS are transmitted at a power equivalent to that illuminating a 50-watt domestic light bulb. These signals have to pass through space and the atmosphere before reaching a satnav receiver, after a journey of 12,600 miles (20,200 km). The tiny antenna of a satnav or mobile phone is hidden inside the case itself. By way of comparison, a TV signal is transmitted from a large tower 10–20 miles (16–32 km) away at most, at a power level of 5000-10,000 watts, to a large roof-mounted antenna.

Each GPS satellite – the network normally comprises 24 satellites, four each in six orbital planes – transmits data that indicate its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are further away than others. The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver. When the receiver has data on the distance to at least four GPS satellites, it can calculate its position in three dimensions by triangulation. There are at least 24 operational GPS satellites at all times plus a number of spares. The satellites, operated and maintained by the US Department of Defense, orbit with a period of 12 hours (two orbits per day) at a height of about 12,600 miles (20,200 km) travelling at around 9000 mph (14,500 kph). Ground stations are used to track each satellite's orbit precisely.

While those of us who enjoy using maps may curse at the idiocy of lorrydrivers following satnav (satellite navigation) directions down impassable country lanes, the Global Positioning System has many beneficial uses, from tracking down terrorists and criminals to navigation on the high seas. A single press of a button can pinpoint one's precise position to within a few feet. Developed by the US military in the 1970s,

the Global Positioning System has been globally available since 1994. It provides location and time information in all weather, anywhere on or above the Earth where there is an unobstructed line of sight to four or more GPS satellites. It is freely accessible by anyone with a GPS receiver (with some technical limitations which are only removed for military users.)

During the Cold War, the USA was concerned by the nuclear threat posed by the Soviet Union, which explains the heavy funding to develop GPS. Accurate determination of launcher and target position was essential for the USAF’s strategic bombers and intercontinental ballistic missiles (ICBMs), and the US Navy’s submarine-launched ballistic missiles. However, when Korean Air Lines Flight 007 was shot down in 1983, after straying accidentally into Soviet air space, President Reagan issued a directive making GPS freely available for civilian use, once it was sufficiently developed, as a common good. The first Block I satellite, for system validation, was launched in 1978, while the first operational Block II satellite was launched in 1989, and the 24th satellite was launched in 1994.

WE ARE SURROUNDED

THERE ARE some 2500 satellites of all types and purpose orbiting the earth. There are also over 8000 items of space ‘junk’ orbiting the Earth consisting of things like nose cones and solar panels from old satellites, an astronaut’s glove, a dropped spanner and more. The first GPS satellite was launched in 1978, and a full global constellation of 24 satellites was achieved in 1994. Each satellite is built to last about ten years, and replacements are constantly being built and launched into orbit from Cape Canaveral Air Force Station, Florida. Each GPS satellite weighs around 2000 pounds (907 kg) and is about 17 feet (5.2 m) across with the solar panels extended. Transmitter power is a mere 50 watts or less. More information about satellites and GPS satellites is available on the NASA website, where you can also track the Navstar network of satellites and see which ones are currently orbiting over your location.

The Gulf War of 1990–1 was the first conflict in which GPS was used for a wide variety of military functions. Civilian applications include clock synchronization with accurate GPS time signals; mobile phones; emergency locations; disaster relief; vehicle navigation and tracking systems; personal

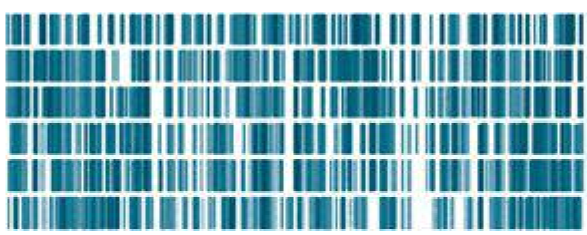
and animal tracking systems; aircraft and ship navigation and tracking; *geotagging* for mapping; mapmaking; surveying; tectonics; robotics; telematics and much more.

DNA SEQUENCING

—— 1979 ——

FREDERICK SANGER B.1918, ENGLAND

Earlier in his career Sanger had invented protein sequencing, leading to nucleic acid sequencing and later the first whole genome sequence. In 1962 Sanger moved to the new UK Medical Research Council Laboratory of Molecular Biology, the premier institution in the world for this new science. Surrounded by researchers interested in DNA and genes, Sanger took up the challenge of determining the order of bases (the basic building blocks) in DNA, known as DNA sequencing. It was clear by this time that DNA was a linear code and that, although the code was being unravelled, no methods existed to read the code in even the simplest genome. Over the next 15 years Sanger's team developed several methods to sequence the nucleic acids DNA and RNA. In the 1970s Sanger and his researchers developed novel techniques of sequencing: the fundamental method of 'reading' DNA using special bases called *chain terminators*, the use of very thin gel systems, the adaptation of efficient cloning methods to produce both DNA strands and whole-genome shotgun data and sequencing (a particular method used for sequencing long DNA strands).



The group produced the first DNA whole genome sequence of just over 5000 base-pairs for a virus called phiX174 that grows in bacteria. It went on to sequence the first human-derived genome (mitochondrial DNA, mtDNA) of 16,569 base-pairs. In 1982 it sequenced the genome of an important virus and model organism for molecular biology, called bacteriophage lambda. To sequence the lambda genome of about 48,000 base-pairs, Sanger developed

the whole-genome shotgun method. In 1980 Sanger was awarded a second Nobel Prize for developing a technique still used today: the *dideoxy* method or *Sanger sequencing*. In this method, stretches of 500–800 bases at a time can be read. Sanger finds it remarkable that a method he developed more than 30 years ago is still in use today, both by scientists at the Sanger Institute and around the world, to sequence genomes up to 3,000,000,000 base-pairs long. A modest man, he declined a knighthood but accepted the Order of Merit, a hugely prestigious honour limited to only 24 members chosen personally by Queen Elizabeth II.

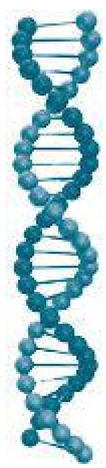
THE GENOME REVOLUTION

THE COST of human genome sequencing has fallen every year, to around $30,000 today. After the first draft of the human genome was published in 2001, in 2002 we saw the launch of the first ‘smart’ cancer drug (Gilvec) to target a specific genetic mutation. The genome of MRSA was sequenced, and a mutation of the BRAF gene was found in half of the cases of malignant melanoma. In 2004 came the launch of next-generation sequencing techniques, faster and cheaper than ‘Sanger sequencing’, and in 2007 companies began selling genetic data directly to consumers. In 2009 geneticists found the cause of Miller syndrome and in 2010 the genetic cause of a bowel disorder was discovered. In 2011 trial results showed that a drug developed to target the BRAF gene prolongs the survival of suitable melanoma patients. Over the coming years, smart drugs will be developed to target the mutations that cause tumours, and screening will allow preventative treatment for many diseases. Also, sequencing the genomes of bacteria such as MRSA (Methicillin-resistant *Staphylococcus aureus*) allows scientists to ‘fingerprint’ different strains to trace and eliminate the sources of outbreaks of disease.

ROSALIND FRANKLIN AND THE STRUCTURE OF DNA 1953

FRANCIS HARRY COMPTON CRICK (1916–2004), James Dewey Watson (b.1928) and Maurice Hugh Frederick Wilkins (1916–2004) won the 1962 Nobel Prize in Medicine. It was awarded for their discovery of the structure of DNA (deoxyribonucleic acid), one of the most significant scientific discoveries of the 20th century. At Cambridge University Watson and Crick

worked together on studying the structure of DNA, the molecule that contains the hereditary information for cell formation. At that time Maurice Wilkins and Rosalind Elsie Franklin (1920–1958), both working at King's College, London, were using X-ray diffraction to study DNA. Crick and Watson used the findings of Wilkins and Franklin in their own research. In April 1953 they published the news of their discovery, the molecular structure of DNA based on all its known features – the *double helix*. Their model served to explain how DNA replicates and how hereditary information is coded on it, setting the stage for the rapid advances in molecular biology that continue to this day.



After a doctorate in physical chemistry at Cambridge, Rosalind Franklin spent three productive years (1947–50) in Paris at the Laboratoire Central des Services Chimiques de L'Etat, where she learned X-ray diffraction techniques. In 1951 she returned to England as a research associate in John Randall's laboratory at King's College, London. In Randall's laboratory, she and Wilkins led separate research groups and had separate projects, although both were concerned with study of DNA. When Randall gave Franklin responsibility for her DNA project, no one had worked on it for months. Wilkins was away at the time, and when he returned he behaved as though she were merely a technical assistant. However, Franklin persisted with her DNA research, and the pioneering crystallographer J.D. Bernal called her X-ray photographs of DNA '*the most beautiful X-ray photographs of any substance ever taken*'. Between 1951 and 1953 Franklin came very close to unravelling the structure of DNA. She was only beaten to publication by Crick and Watson because of the friction between Wilkins

and herself. Wilkins showed Watson one of Franklin's crystallographic portraits of DNA. When Watson saw the picture, the solution became apparent to him, and the results went into an article in *Nature* almost immediately. Franklin's work only appeared as a supporting article in the same issue of the journal. A scientist of the first rank, Franklin happily left the laboratory she shared with Wilkins, moving to J.D. Bernal's lab at Birkbeck College in London to research the tobacco mosaic virus. She also began research work on the polio virus. In the summer of 1956 the 35-year-old Franklin became ill with breast cancer. She died less than two years later, and the Nobel Prize could not be awarded posthumously.

MICROSOFT OPERATING SYSTEMS

—— 1981 *onwards* ——
WILLIAM HENRY 'BILL' GATES B.1955, UNITED STATES

By means of shrewd business deals, Gates made *Windows* the world's most popular operating system for computers. The *operating system* (OS) is the foundation software of a computer. The OS schedules tasks, allocates storage and presents a default interface between different applications. While a computer is now relatively easy to build and copy, its software is the key to its public, industrial and commercial acceptance. Fairly rapidly, Microsoft software became the most accepted global software. With nearly all users understanding how to use Microsoft software, computers became cheaper and cheaper commodities. Importantly, with everyone wanting to use the same software, market power in the computer industry became concentrated in Microsoft. It updates its software every few years, ensuring that people and companies pay more money for the newer versions. As teenagers Bill Gates and Paul Allen (b.1953) ran a small company called Traf-O-Data, and they sold a computer to the Seattle authorities to count city traffic. Gates then was a student at Harvard University, where he met Steve Ballmer (now CEO of Microsoft). While there, Gates wrote a version of the programming language BASIC for the MITS *Altair* microcomputer. In 1975 he left Harvard before graduating to form Microsoft with Paul Allen and develop software for the emerging personal computer (PC) market.

IBM was by some distance the world's most important commercial and industrial computer manufacturer, and the company decided to move into the new market of personal computing. It approached Microsoft to discuss the state of the new home computer market and Microsoft products. Gates gave IBM some ideas on what would constitute a good PC, including having BASIC written into the ROM microchip. Microsoft had never written an OS (operating system), so Gates suggested that IBM talked to Gary Kildall, the founder of Digital Research. Kildall (1942–1994) was one of the first to recognize that new microprocessors were capable of being fully capable computers, rather than equipment controllers, and to organize a company around this idea. Kildall had written the most successful OS for small computers, *CP/M* (Control Program for Microcomputers), which had set the industry standard. However, IBM and Kildall failed to agree terms. IBM then offered Microsoft the contract to write the new OS for their forthcoming personal computer, the *IBM PC*. Tim Paterson of Seattle Computer Products had written a clone of Kildall's CP/M for its prototype Intel 8086-based computer in just six weeks. Paterson called it the *QDOS* (Quick and Dirty Operating System). Gates and Allen quickly bought the rights to QDOS for only $50,000, keeping their IBM contract for an OS a secret from Paterson and Seattle Computer Products.

Their 'Microsoft Disk Operating System', *MS-DOS*, was based on QDOS. In 1981 Paterson left Seattle Computer Products to join Microsoft. In the same year, IBM introduced its new '*revolution in a box*', the IBM PC (Personal Computer). It came complete with a new 16-bit computer operating system from Microsoft, called *MS-DOS 1.0*. (However, IBM called its identical software *PC-DOS*.) Kildall soon obtained a copy of MS-

DOS 1.0, examined it, and decided that it infringed his original CP/M operating system. However, he was legally advised that the infant intellectual property laws for software were not clear enough to allow him to sue. Also IBM could afford the best patent lawyers. Additionally, Microsoft and IBM claimed that MS-DOS could be legally considered a different product. Cleverly, Gates was allowed to retain the licensing rights to market MS-DOS separately from the IBM PC and its PC-DOS. Microsoft now proceeded to make a fortune from the licensing of MS-DOS to the makers of cheaper IBM PC-compatible computers. Across the world people learned how to use PC-DOS in office applications. However, they increasingly bought for home, and then office use, these far cheaper IBM-compatible computers, running Microsoft MS-DOS software. IBM no longer had a unique product, and cheaper, better PCs started eating into its market share. Eventually IBM left the cutthroat home computer hardware market, while all its competitors were licensing Microsoft software.

In November 1983 Microsoft formally announced Microsoft *Windows*, a much improved operating system that provided a graphical user interface (GUI) and a multitasking environment for IBM and compatible computers. Gates demonstrated a beta version of Windows to IBM, but met with a poor response. IBM was working on its own new OS, having learned its lesson from its original MS-DOS deal with Microsoft. IBM released *Top View* in February 1985, as a DOS-based multitasking program manager, but without any GUI features. Unpopular and expensive, Top View was discontinued two years later. Gates knew, from seeing Apple Computer's *Lisa*, *Macintosh* and *Mac* computers that a GUI was a great leap forward for users. The Macintosh operating system, *Mac OS*, featured the innovations of windows, mice, drop-down menus and pointers, making it far easier to operate these computers. Microsoft finally released *Windows 1.0* in November 1985, but it was considered crude, slow and prone to bugs. Apple threatened legal action for stolen trade secrets, copyright and patent infringements in September 1985. Gates then offered to license Apple's OS, and a contract was agreed with Apple. Again Gates worded the contract in his favour. Microsoft could use Apple features not just in Windows version 1.0, but in all future Microsoft software programs. In 1987 Windows made its breakthrough with the release of a Windows-compatible program, *Aldus PageMaker 1.0*, the first WYSIWYG (what you see is what you get) desktop-publishing programme. In the same year, Microsoft released the

Windows-compatible spreadsheet *Excel*. Microsoft *Word* and *Corel Draw* followed, to make Windows software a ‘must have’ for all non-Apple computer users. *Windows 2.0* in 1987 added icons to represent files and programs.

YOU CAN’T TAKE IT WITH YOU…

BILL GATES IS no longer the planet’s richest person, because he has given away $30 billion to his charitable foundation. In 2008 Gates left his day-to-day role with Microsoft to focus on philanthropy. Holding that all lives have equal value, the Bill and Melinda Gates Foundation has donated massive sums to HIV/AIDS programmes, libraries, agriculture research, health, education and disaster relief. With help from the billionaire Warren Buffett, Gates has convinced nearly 60 of the world’s wealthiest people to sign his *Giving Pledge*, promising to donate the majority of their wealth to various charitable causes either during their lifetime or after their death.

Apple took legal action in 1988, alleging that Microsoft had broken the 1985 licensing agreement and had infringed 170 of their copyrights. Microsoft claimed that the licensing agreement gave them the rights to use innovative Apple features, and after a costly four-year court case, Microsoft won. Programmers across the world were now writing Windows-compatible software, giving end-users a reason to buy the next *Windows 3.0* software, of which three million copies were sold the first year. In 1992 *Windows 3.1* was released and it sold three million copies in the first two months. *Windows 95* was a massive success, and *Windows 98* was the first version not to be based on the MS-DOS kernel. It had *Internet Explorer 4* built in, and supported USB input devices. *Windows 2000, Windows XP* (2001) and *Windows Vista* have consolidated Microsoft’s present stranglehold on computer operating systems.

SPACE SHUTTLE

—— 1981–2011 ——

NASA SCIENTISTS AND CONTRACTORS, UNITED STATES

This *reuseable spacecraft* has carried people into orbit repeatedly, launched, recovered and repaired satellites, conducted cutting-edge research

and been used to help build the largest structure in space, the International Space Station. As the first reusable spacecraft, the space shuttle has pushed the bounds of discovery ever further, stimulating the development of advanced technologies. NASA's shuttle fleet achieved numerous firsts and opened up space to more people than ever before. Officially called the *Space Transportation System* (STS), it began its flight career when *Columbia* blasted off from NASA's Kennedy Space Centre in Florida on 12 April 1981. The first mission verified the combined performance of the orbiter vehicle (OV), its twin solid rocket boosters (SRBs), massive external fuel tank (ET) and three main engines (SSMEs). The space vehicle system had about two and a half million moving parts. The orbiter vehicle, most commonly referred to as the *space shuttle*, was the only part of the shuttle *stack* that made the trip into orbit. The boosters (SRBs) were jettisoned into the Atlantic Ocean, retrieved and reused. The external tank (ET) was the only part of the stack not used again, as it reentered the atmosphere about nine minutes after launch and burnt up over the Indian or Pacific Ocean depending on the launch profile. When the shuttle returned to Earth, it did not float down under parachutes like the *Apollo* manned capsules which preceded it. Instead, it returned by gliding back like an aircraft to a runway in the United States. The shuttle had a 60-foot (18.3-m-) long payload bay and robotic arm that could extract satellites from the payload bay and release them into low Earth orbit, help astronauts to service them and even bring them back for future use. The shuttle fleet, which was designed to reach orbits ranging from about 115 to 400 miles (185 to 644 km) high, also routinely carried whole laboratories into orbit for unique experiments. It was called on to build the International Space Station (ISS), the largest spacecraft ever, which was assembled in orbit. The shuttle programme cost $113.7 billion, not adjusted for inflation.

Enterprise was the first space shuttle, although it never flew in space. It was used to test critical phases of landing and other aspects of shuttle preparations. *Columbia* was the first shuttle to fly into orbit as mission STS-1. Astronauts operated the robotic arm and put all the flight systems through evaluation phases during the test flights. *Columbia* deployed numerous satellites and operated several times as a laboratory in space during its missions. However, *Columbia* and its seven astronauts were lost in 2003, when it broke apart during re-entry on its 28th mission. *Challenger* was the second operational shuttle and made its first flight, STS-6, in 1983. *Challenger* undertook missions that saw astronauts take the first-ever spacewalks equipped with jetpacks, and also the first mission to retrieve a satellite out of orbit, fix it in the payload bay and return it to service. On its tenth mission in 1986, *Challenger* and its seven astronauts were tragically lost when a seal on one of its boosters failed and hot gas burned through the external tank, so igniting the liquid propellants inside and causing the shuttle to break up in the resulting catastrophic explosion.

NASA SHUTTLE STATS

	Flights	Earth Orbits	Miles Travelled	Time in Space (days, rounded)
Columbia	28	4808	121,696,933	301
Challenger	10	995	23,661,290	62
Discovery	39	5830	148,221,675	365
Endeavour	25	4671	122,883,151	299
Atlantis	33	4848	120,650,907	294
Total	135	21,152	537,113,956	1321

Discovery made its first flight, STS-41D, in 1984. *Discovery* flew more than any other shuttle with 39 missions. *Discovery* deployed NASA's Hubble Space Telescope, which has altered the way we see and think of our Universe. *Endeavour*'s first mission was in 1992, STS-49. During this, three spacewalking astronauts made the unprecedented effort to grab an orbiting satellite with their gloved hands and pull it into *Endeavour*'s cargo bay. It was then repaired with a new motor and re-launched from the shuttle. *Endeavour* also accomplished the first repair mission to NASA's Hubble Space Telescope, basically giving the telescope new instruments so that it could peer to the furthest edges of the Universe. *Atlantis* made its first flight, STS-51J, in 1985. The shuttle sent probes to Venus and Jupiter and carried NASA's *Destiny* laboratory to the International Space Station. *Atlantis* also served as the final shuttle servicing mission, STS-135, for NASA's Hubble Space Telescope. It was launched on 8 July 2011 and made the final landing at Kennedy Space Center in Florida on 21 July.

ARTIFICIAL HEART

—— 1982 ——

WILLEM JOHAN KOLFF 1911–2009, HOLLAND AND UNITED STATES

After developing the kidney dialysis machine, Kolff moved from Holland to the United States in 1950 in search of better opportunities. Here, he headed a team which invented and tested an artificial heart. At the Cleveland Clinic in Ohio, he was involved in the development of heart-lung machines to oxygenate blood, and to maintain heart and pulmonary function, during cardiac surgery. He also constantly improved his dialysis

machine. In 1957 Kolff and a colleague became the first western medical researchers to implant an artificial heart in a dog. In 1982, in Salt Lake City, Utah, a retired dentist, Barney Clark, became the first human to receive a surgically implanted artificial heart. It had been developed at the Institute for Biomedical Engineering at the University of Utah, where Kolff had been director since 1967, and where the institute's pioneering work had led him to be dubbed the 'father of artificial organs'. The first artificial heart for human use had been developed using Kolff's principles. The developer was Dr Jarvik, and the first heart transplant surgery was performed by Dr William C. DeVries. The heart received by Mr Clark was named the *Jarvik-7* artificial heart device. Clark lived only 112 days and suffered a series of convulsions. He did not die of a heart attack or a stroke, but the implant procedure's ethics generated a huge controversy. Kolff had already found that the very idea of artificial organs offended some people, including doctors. He recalled that once, in the men's lavatory at the US National Institute of Health, '*one of the top men there looked back over his shoulder at me and said: "I hope the artificial heart will never work." He thought you shouldn't do a thing like that. That's also why it's difficult to get support. Nobody wants an artificial heart – unless they're going to die two days from now.*' Kolff's patent was for a *Soft Shell Mushroom Shaped Heart: Artificial Heart:* Patent Number 3,641,591.

Kolff also carried out research which showed that the electrical stimulation of certain parts of the brains of blind people could produce the sensation of seeing points of light. His research bore fruit when in 1999 his collaborator William Dobelle fitted a Brooklyn man with the world's first

artificial eye. Kolff directed research into artificial eyes, artificial hearing, electronically controlled arms, and the membrane oxygenator and, even after he retired at 75, he continued experimenting. After 60 years of marriage, he separated from his wife, his inability to give up making things with pipes and tubes all over the home having proved too much for her. Even in his nineties, living as a divorced man in a one-room flat in a home for the elderly in a Philadelphia suburb, he was working on a portable artificial lung with the backing of a German manufacturer. In his lifetime Kolff won many awards, one worth $500,000, which he used to develop his portable lung, and he contributed more than 300 articles to journals. In his old age his dialysis machines were estimated to be keeping one million people alive around the world.

POLYMERASE CHAIN REACTION (PCR)

—— 1983 ——

KARY BANKS MULLIS B.1944, UNITED STATES

Polymerase chain reaction (PCR) is a chemical procedure that allows scientists to ‘see’ the structures of the molecules of genes, thereby advancing the fields of molecular biology, molecular palaeontology, biotechnology, forensics, medicine and genetics. With a doctorate in biochemistry from University of California, Berkeley, Mullis became a medical researcher before joining the Cetus Corporation as a DNA chemist in 1979. During his seven years there, he conducted research on oligonucleotide synthesis. Mullis received the Nobel Prize in Chemistry in 1993 for his invention of the polymerase chain reaction. The process, which he had conceptualized in 1983, is one of the monumental scientific techniques of the 20th century. A method of amplifying DNA, PCR multiplies a single, microscopic strand of the genetic material billions of times within hours. PCR amplifies specific DNA sequences from very small amounts of complex genetic material. The amplification produces an almost unlimited number of highly purified DNA molecules suitable for analysis or manipulation. PCR has allowed screening for genetic and infectious diseases, while analysis of DNA from different populations, including DNA from extinct species, has allowed the reconstruction of phylogenetic family

trees including those of primates and humans. PCR is essential to forensics and paternity testing.

THE VALUE OF A NOBEL PRIZE

IN SPRING 1983 Mullis was driving his car late one night with his girlfriend, who was also a chemist at Cetus. Suddenly he had the idea to use a pair of primers to bracket the desired DNA sequence and to copy it using DNA polymerase, a technique which would allow a small strand of DNA to be copied almost an infinite number of times. Cetus took Mullis off his usual projects to concentrate on PCR full-time. Mullis succeeded in demonstrating PCR on 16 December 1983. However, in his Nobel Prize lecture, he stated that this success did not make up for his girlfriend breaking up with him shortly before: 'I *was sagging as I walked out to my little silver Honda Civic. Neither Fred* [his assistant], *empty Beck's bottles, nor the sweet smell of the dawn of the age of PCR could replace Jenny. I was lonesome.*' Emily Yoffe, '*Is Kary Mullis God? Nobel Prize winner's new life*', *Esquire*, July 1994

The process has multiple applications in the fields of medicine, genetics, biotechnology and forensics. Because of its ability to extract DNA from fossils, PCR is also the basis of a new scientific discipline, paleobiology. PCR is also used in testing for AIDS. The breakthrough made by Mullis allowed PCR to become a central technique in biochemistry and molecular biology, and was described by *The New York Times* as '*highly original and significant, virtually dividing biology into the two epochs of before P.C.R. and after P.C.R.*' In 1986 Mullis was named director of molecular biology at Xytronyx, Inc. in San Diego, where his work concentrated on DNA technology and photochemistry. In 1987 he began consulting on nucleic acid chemistry for more than a dozen corporations. Mullis's patents include PCR technology and UV-sensitive plastic that changes colour in response to light. His most recent patent application covers a revolutionary approach to instantly mobilize the immune system to neutralize invading pathogens and toxins, leading to the formation of his latest venture, Altermune LLC. Altermune is currently focusing on influenza A and drug-resistant *Staphylococcus aureus*.

EDIBLE MYCOPROTEIN

—— 1985 ——
(***when marketed as 'Quorn'***)
RHM AND ICI SCIENTISTS, BUCKINGHAMSHIRE, ENGLAND

This vegetarian alternative to meat may be the precursor of our main source of protein in future food shortages. Growing animals for food is an incredibly wasteful use of scarce resources, which cannot be sustained if the world population keeps rising at its current rate. The increased meat consumption as India and China, which contain 40 per cent of the world's population, become richer will exacerbate the problem. Over-population is the Earth's worst crisis. As early as the 1960s, it was predicted that by the 1980s there would be a shortage of foods for stock animals as well as humans. It takes ten times as many crops to feed animals being bred for meat production, as it would to feed the same number of people on a vegetarian diet. Currently, 70 per cent of all the wheat, corn and other grain produced is fed to farmed animals. (Incidentally, direct emissions from meat production account for about 18 per cent of the world's total greenhouse gas emissions.) In Europe especially, with less land per capita than, say, the USA or Canada, research studies were undertaken to use single-cell biomass as an animal feed. However, Rank-Hovis-McDougall's Research Centre in Marlow, Buckinghamshire took a different direction. It looked into converting starch (the waste product of RHM's cereal manufacturing) into a protein-rich food for human consumption.

The filamentous fungus (or mould), *Fusarium venenatum*, was only discovered in soil in 1967, but after screening it was isolated as the best

candidate for development of this idea. It was grown in large vats as part of a joint venture between RHM and ICI, which provided a large fermentation vat which had been left empty from its abandoned single-cell feed programme. The two partners invested patents for growing and processing the fungus, and in 1985 RHM was given permission to sell what they termed *mycoprotein*, branded as *Quorn*, for human consumption. The food sold well in the initial test market of the RHM staff canteen, but large supermarket chains were not convinced until Sainsbury's decided to stock the new brand. Quorn was marketed as a healthy alternative to meat, free from animal fats and cholesterol, and it has been relatively successful. Most supermarkets now have vegetarian and meat-substitute sections. Quorn is produced as both a cooking ingredient and as a range of health-food meals. It uses egg-white as a binder, so is not suitable for vegans. As well as Quorn there are other meat substitutes available for vegetarians. Textured vegetable protein, or TVP, is simply defatted soy flour. Tofu has been used in China since 200 BCE. Tempeh is made from fermented soybeans and other grains.

VEGGIE STREET MAPS

IN MAY 2009 the city of Ghent in Belgium was reported to be '*the first in the world to go vegetarian at least once a week*'. It did so for environmental reasons, after local authorities decided to implement a 'weekly meatless day'. Civil servants and schoolchildren were to eat vegetarian meals one day a week in recognition of a United Nations' report on food production and health. Posters were put up by local authorities to encourage the population to take part in vegetarian days, and 'veggie street maps' were printed to highlight local vegetarian restaurants.

HUMAN GENOME PROJECT – THE MAPPING, SEQUENCING AND IDENTIFICATION OF GENES

—— 1989 *onwards* ——

CHARLES DELISI B.1941, UNITED STATES

The Human Genome Project provides clues to the understanding of human biology. Knowledge of the effects of DNA variation among

individuals can revolutionize ways to diagnose, treat and even prevent a number of diseases. The human genome was first completely sequenced in 2001, but research carries on. The human genome is the genome of our species, *Homo sapiens*, that is stored on 23 chromosome pairs plus the small mitochondrial DNA. Of these 23 chromosomes, 22 are autosomal chromosome pairs, while the remaining pair determines sex. The human genome occupies a total of just over three billion DNA base pairs, and around 23,000 protein-coding genes, far fewer than was thought when sequencing began. DeLisi is now Metcalf Professor of Science and Engineering at Boston University in Massachusetts, but in 1985 was he was director of the US Department of Energy's (DOE) Health and Environmental Research Programs. In this capacity, DeLisi and his advisors proposed, planned and defended the Human Genome Project (HGP) before Congress and the White House Office of Management and Budget. The Project developed into a massive international scientific research effort.

The Human Genome Project was started in 1989 with the aim of sequencing and identifying all three billion chemical units in the human genetic instruction set. With the sequence in hand, the next step was to identify the genetic variants that increase the risk for common diseases like cancer and diabetes. Our genome has 23 pairs of chromosomes. Each chromosome is a long string of beads, but unlike a string of beads it is not joined together at the ends. There are only four different coloured beads representing the four bases, A, G, C and T, and these are all that DNA needs to construct our entire genome. There are three billion bases in one human genome and each cell in our body has double this number (as we inherit a copy from each parent). It is the order, or sequence, of these bases that defines our genes, lets our cells know to turn genes on and off and, in fact, makes us human. Changes to the sequence of these bases cause genetic

disease. These changes can be complex, for example, deletions of large tracts of bases, or simple, just a substitution of one base for another. ‘DNA variants’ arising from base substitutions are a normal part of the human genome and if any two genomes were compared, there would be around three million of these changes found. Some common base substitutions may be found in between five and 40 per cent of the population, whereas others are rare. Hundreds of new DNA variants that ‘cause’ the genetic part of common diseases have been discovered, but there is much more research to be carried out to scientifically describe most of the genetic basis of these diseases.

THE PRESIDENTIAL CITIZEN’S MEDAL

IN 1985, DELISI read a government report on technologies to detect inherited mutations in children who had been exposed to the Hiroshima and Nagasaki bombs. He conceptualized a concerted effort to sequence the human genome, under the aegis of the US Department of Energy. DeLisi was ideally positioned to galvanize his idea through the provision of money and resources. While this was the third public airing of the idea, it was DeLisi’s energy and his position in government science administration that effectively launched the genome project. As a result, thousands of scientists across the world worked for 13 years, following his proposals for mapping, sequencing and identifying human genes.

In recognition of his inspiring work, in 2001 President Clinton presented DeLisi with the Presidential Citizen’s Medal. President Clinton said: ‘*Just as Lewis and Clark set forth to explore a continent shrouded in mysterious possibility, Charles DeLisi pioneered the exploration of a modern day frontier, the human genome…Charles DeLisi’s imagination and determination helped to ignite the revolution in sequencing that would ultimately unravel the code of human life itself. Thanks to Charles DeLisi’s vision and leadership, in the year 2000 we announced the complete sequencing of the human genome. And researchers are now closer than ever to finding therapies and cures for ailments once thought untreatable.*’ DeLisi’s citation reads: ‘*A pioneer and visionary, biophysicist Dr. Charles DeLisi has profoundly increased our knowledge about the building blocks of life. The first government scientist to outline the feasibility, goals, and parameters of the Human Genome Project, he helped to galvanize an*

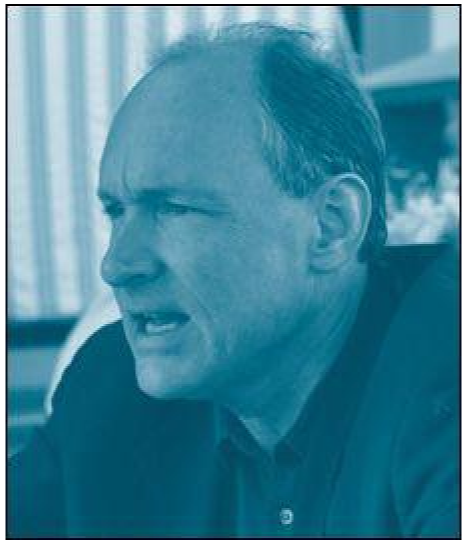
international team of researchers to pool resources, create new technologies, and launch the monumental task of gene mapping and sequencing.’

Detailed knowledge of the human genome is opening new avenues for advances in biotechnology and medicine. Companies and hospitals can now offer simple ways to administer genetic tests that can show predisposition to a variety of illnesses, including liver diseases, cystic fibrosis, haemostasis disorders (when bleeding does not stop), breast cancer and many others. Also the causes of cancers, Alzheimer’s disease and other areas of clinical interest will be better understood as a result of genome information, hopefully leading in the long term to significant advances in their management. In biological research, if a scientist investigating a particular type of cancer has narrowed the search to a particular gene, he or she can use the human genome database on the World Wide Web to check what other scientists have written about the gene, its relationships to other genes etc. Better understanding of disease processes at the level of molecular biology will determine new therapeutic procedures. The results of the HGP are being used across the globe by clinicians, researchers and scientists to improve the health of mankind.

WORLD WIDE WEB

—— 1990 ——

TIMOTHY JOHN BERNERS-LEE B.1955, ENGLAND, AND ROBERT CAILLIAU B.1947, BELGIUM



This is the key technology that popularized the Internet and revolutionized communications. Tim Berners-Lee, a British computer scientist, engineer and MIT professor, is credited with the first proposal for a *world wide web*, but it was developed jointly with the Belgian informatics engineer Robert Cailliau. Both were working at CERN (the European Organization for Nuclear Research), when in March 1989 Berners-Lee proposed a system that would allow easier access to the huge amount of CERN documentation. He had found it frustrating that there was different information on different computers, but users had to log on to different computers to get at it, and sometimes they had to learn a different program on each computer. In 1980 Berners-Lee had created ENQUIRE, an early *hypertext* database system resembling what we now call a ‘wiki’. The new CERN information system was also to be hypertext, displayed upon a computer with *hyperlinks* (references) to other hypertext documents, which could be immediately accessed by a mouse click or a keystroke sequence. Hypertext documents can either be static (prepared and stored in advance) or dynamic (continually changing in response to user input). Hypertext can also contain drawings, images, tables and presentational devices, and is the fundamental concept giving structure to the World Wide Web. Berners-Lee created what he defined as World Wide Web between September and December 1990, while he and Cailliau coauthored a proposal to fund the project. Its ease of use and flexible format enables all of us to share information over the Internet. On 25 December 1990, with the help of Cailliau and a young student at CERN, Berners-Lee implemented the first

successful communication between a Hypertext Transfer Protocol (HTTP) client and server, via the Internet.

TA-DA!

'*When I was doing the WWW, most of the bits I needed were already done…I just had to take the hypertext idea and connect it to the TCP* [Transmission Control Protocol] *and DNS* [Domain Name System] *ideas and – ta-da! – the World Wide Web.*' This was Tim Berners-Lee's answer in response to the question '*Did you invent the Internet*' on the *Answers for Young People* webpage, www.w3.org.

WorldWideWeb was the first web *browser*, written by Berners-Lee, and at the time the only way to access information on the World Wide Web. It was later renamed *Nexus* to overcome confusion with the World Wide Web itself. Cailliau became a key proponent in World Wide Web development and later designed the first web browser for Apple, called MacWWW. Berners-Lee understood that a private monopoly would have restricted the growth of the web, and so he managed to get CERN to provide certification on 30 April 1993 ensuring that web technology and program code was in the public domain, whereby anyone could use and improve it. His foresight and lack of greed changed communications and information technology forever, enabling the appearance of emails, Google, Facebook, Twitter, Wikipedia etc. In December 1993 Cailliau called for the first International WWW Conference, held at CERN in May 1994. The attendance of 380 web pioneers was a milestone in the development of the web. Now over two billion people, around a third of the world's population, are Internet users.

INTERNET RETAILING

—— 1995 *onwards* ——

Jeffrey Preston Bezos b.1964, United States

Having already revolutionized the way the world buys books, Jeff Bezos (born Jorgensen) is now also transforming the way we read them with *e-books* and the *Kindle* e-book reader. Bezos graduated from Princeton University with a degree in computer science and electrical engineering, and found employment on Wall Street, where computer science was

increasingly in demand to analyze market trends. He became a vice-president at Bankers Trust, then a senior vice-president at D.E. Shaw, a firm specializing in the application of computer science to the stock market. The fledgling Internet (the ARPANET) had been originally created by the US Defense Department to keep its computer networks connected during an emergency, such as a natural catastrophe or enemy attack. It had been adopted by government and academic researchers to exchange data and messages, but in 1994 there was still no Internet commerce to speak of. Bezos observed that Internet usage was increasing by 2300 per cent per annum, and spotted an opportunity for a new sphere of business. He methodically reviewed the top 20 mail order businesses, and asked himself which could be conducted more efficiently over the Internet. Books were the commodity for which no comprehensive mail order catalogue existed, because any such catalogue would be too big to mail. However, books were perfect for the Internet, which could share a vast database with a virtually limitless number of people.

He found that the major book wholesalers had already compiled electronic lists of their inventory. All that was needed was a single location on the Internet where the book-buying public could search the available stock and place orders directly. He moved to Seattle, Washington State to have ready access to the large book wholesaler Ingram, and to draw on the pool of computer talent needed for his enterprise – Microsoft was based in Seattle too. The company would be called Amazon after the vast South American river with its numberless tributaries. In 1995 Bezos unveiled his new website to the world, and told 300 beta testers to spread the word. In 30 days, with no press, Amazon had sold books in 50 American states and 45 foreign countries. By September, it had sales of $20,000 a week. Bezos and his team continued improving the site, introducing new features such as *1-click shopping*, customer reviews and email order verification. When the company went public in 1997, analysts wondered if an Internet-based start-up bookseller could maintain its position once retail bookselling giants like Barnes and Noble or Borders began Internet retailing (Borders has since gone into administration). Two years later, the market value of shares in Amazon was greater than that of its two biggest retail competitors combined, and Borders was contacting Amazon to ask it to handle its Internet traffic.

From the beginning, Bezos sought to increase market share as quickly as possible, at the expense of profits. Everything was ploughed back into making the business model of Amazon impossible to replicate. When he disclosed his intention to go from being '*Earth's biggest bookstore*' to '*Earth's biggest anything store*', critics were divided. Some thought Amazon was growing too fast, but others called it '*one of the smartest strategies in business history*'. Bezos continually emphasized Amazon's '*Six Core Values: customer obsession, ownership, bias for action, frugality, high hiring bar and innovation.*' He stated '*Our vision is* [to be] *the world's most customer-centric company. The place where people come to find and discover anything they might want to buy online.*' Amazon quickly moved into music CDs, videos, toys, electronics and more. When the recession deepened in 2000, Amazon's stock plummeted. However, Amazon restructured, and while other dot.com start-ups evaporated, Amazon began making substantial profits. In 2002 the firm added clothing sales to its line-up, through partnerships with hundreds of retailers including The Gap, Nordstrom and Land's End. Amazon shares its expertise in customer service and online order fulfilment with other vendors through co-branded sites, such as Toys 'R' Us, and through its Amazon Services subsidiary. Amazon is now the world's largest online retailer, with nearly three times the sales of is nearest rival, the office supplier Staples.

THE COST OF SECURITY

AMAZON ONLY paid its CEO Bezos a salary of $81,840 in 2010, but his security detail cost $1.6 million for the year. In filing its proxy accounts an Amazon spokesman explained the cost, saying, '*We believe that the amount of the reported security expenses is especially reasonable in light of Mr. Bezos' low salary and the fact that he has never received any stock-based*

compensation.' As Bezos still owns 20 per cent of Amazon, he does not really need small sums of stock, nor a large salary.

In 2007 Amazon introduced a handheld electronic reading device called the *Kindle*. The device uses *E Ink* technology to render text in a printlike appearance, without the eyestrain associated with television and computer screens. Font size is adjustable for further ease of reading, and unlike earlier electronic reading devices, the Kindle incorporates wireless Internet connectivity, enabling the reader to purchase, download and read complete books and other documents anywhere, anytime. With the introduction of the Kindle, Amazon quickly captured 95 per cent of the US market for books in electronic form, *e-books*. One model works with WiFi, and a second adds G3 mobile connectivity. By mid-2010, Kindle and e-book sales had reached $2.38 billion a year, and Amazon's sales of e-books topped its sales of traditional hardcover titles. With e-book sales increasing by 200 per cent a year, Bezos has predicted that e-books will overtake paperbacks and become the company's bestselling format within a year. In 2000 Amazon's recorded losses of $1.4 billion had made it, as Richard Brandt noted in his book *One Click*, '*the biggest money loser on the Internet*', moving from '*Internet poster child to Internet whipping boy*'. By 2010 Amazon was worth over $80 billion, simply because of the strength of the model of business that Bezos had developed.

GOOGLE INTERNET SEARCH ENGINE

—— 1996 ——

LAWRENCE 'LARRY' PAGE B.1973 AND SERGEY MIKHAYLOVICH BRIN B.1973, UNITED STATES

The Google search engine is the most dominant website in the world. It is used by around one in seven of the world's population. Search engines are programs that search the Internet and find webpages for the user, based upon keywords submitted by the user. A typical search engine uses spider software including Boolean operators, search fields, display format, a massive database and algorithms that rank results for relevancy. In 1995 Larry Page and Sergey Brin met at Stanford University as graduate students in computer science. By January 1996 they were writing a program for a

search engine they called *BackRub*, named after its ability to carry out backlink analysis. To convert the backlink data gathered by BackRub's web crawler into a measure of importance for any given webpage, the pair developed the *PageRank* algorithm. They realized that it could be used to build a search engine far superior to existing ones. Their innovation relied on a new kind of technology, which analyzed the relevance of the back links that connected one webpage to another. Because of the favourable response to BackRub, they then began working on *Google*. They built a server network using cheap, used and borrowed PCs, and used a variety of credit cards to buy terabytes of disk memory at discount prices. In August 1996 the initial version of Google was made available, still on the Stanford University website.

Needing more funding, they failed to find anyone who wanted their product at its early stage of development, so then tried to license their search engine technology. However, Page and Brin finally decided to keep Google, seek more financing, improve the product, and market it themselves. After more development Google finally became a commercial commodity. The co-founder of Sun Microsystems, Andy Bechtolsheim, said in 1997 after a quick demo of Google: '*Instead of us discussing all the details, why don't I just write you a cheque?*' He made out a $100,000 cheque to Google Inc., but Google Inc. as a legal entity did not exist. Page and Brin quickly incorporated within two weeks, cashed the cheque, and raised $900,000 more for their initial funding. In September 1998 Google Inc. opened in Menlo Park, California and google. com, a beta search engine, was soon answering 10,000 search queries every day. On 21

September 1999 Google officially removed the beta (test status) from its title. In May 2011 unique visitors to Google surpassed the 1 billion mark for the first time, an 8.4 per cent increase from May 2010 which registered 931 million unique visitors. This means that one in seven people on the planet are using Google to obtain information every day. It has totally transformed information technology. Google is also involved in the new technology of *cloud computing* and generates 99 per cent of its income through its *Adwords* program associated with each search that users carry out. Google is constantly expanding its operations, having recently launched the Google *Chrome* web browser. Google *Search* is by far the most dominant search engine in the world. As of 2011 Page and Brin are each calculated to be worth $19.8 billion.

THE GOOGOL

GOOGLE WAS named after a *googol* – the name for the number 10^{100} which is written by 1 followed by 100 zeros. Other names for googol include ten duotrigintillion. It was introduced in the popular book *Mathematics and the Imagination* (1940) by Edward Kasner and James Newman. To Google's founders, the name represented the immense amount of information that a search engine has to sift through. A *googolplex* is even larger: it is 10^{googol}. The astronomer and television personality Carl Sagan estimated that writing a googolplex in numerals would be physically impossible, since doing so would require more space than the known Universe provides.

CLONING OF MAMMALS

—— 1996 ——

IAN WILMUT B.1944 AND KEITH H.S. CAMPBELL B.1954, ENGLAND

The technique has long-term implications for breeding livestock and for reviving extinct species. *Dolly* (1996–2003) was a female Finnish-Dorset sheep, the first mammal to be cloned from an adult somatic cell (i.e. any biological cell forming the body of an organism), using the process of nuclear transfer. Born at Edinburgh's Roslin Institute, she became known as 'the world's most famous sheep'. The production of a healthy clone proved

that a cell taken from a specific part of the body could recreate a whole individual. Dolly had three ‘mothers’, one providing the egg, another supplying the DNA and a third carrying the cloned embryo through pregnancy. Dolly was cloned using the process of somatic cell nuclear transfer. The cell nucleus from an adult cell is transferred into an unfertilized oocyte (a developing egg cell) from which the nucleus has been removed. The hybrid cell is then stimulated to divide by an electric shock, and develops into a blastocyst (an embryonic cell) which is implanted in a surrogate mother. Dolly’s existence was not announced to the public until 1997.

She was mated with a Welsh Mountain ram, and produced a lamb in 1998, twins in 1999 and triplets in 2000. After cloning was successfully demonstrated, many other large mammals have been cloned, including horses and bulls. Cloning of domesticated animals could be important in the future production of better livestock. Cloning will have uses in preserving endangered species and may become a viable tool for reviving extinct species such as mammoths, as mammoth cell tissue still survives frozen in permafrost. Scientists in Spain are working to clone the Pyrenean ibex, declared extinct in 2000. Wilmut has moved away from cloning research as he believes that a different Japanese technique may have more success in the long term. The reprogramming process cells need to go through during cloning is not perfect, and embryos produced by nuclear transfer often show abnormal development, making cloning mammals highly inefficient. Wilmut announced in 2007 that the nuclear transfer technique may never be sufficiently efficient for use in humans. Dolly was the only lamb that survived to adulthood from 277 attempts. Upon her survival, the research team had to give her a name. Wilmut stated humorously, ‘*Dolly is derived from a mammary gland cell and we couldn’t think of a more impressive pair of glands than Dolly Parton’s.*’

WIKIPEDIA

—— 2001 ——

JIMMY DONAL WALES B.1962 AND LAWRENCE MARK SANGER B.1968, UNITED STATES

This has been an amazing breakthrough, a free online encyclopaedia available to the world. In 1996 Wales and two partners founded Bomis, a web portal featuring user-generated webrings. It had struggled to make money, but provided him with the funding to pursue his objective of an online encyclopaedia. Wales was devoted to the philosophy of Objectivism, and he met the philosopher Larry Sanger in the early 1990s while moderating an online discussion group devoted to the subject. Sanger did not agree with Wales's views, but in the course of debating over the years the two became friends. Some years later, still following his encyclopaedia project and needing someone with academic credentials to lead it, Wales hired Sanger as editor-in-chief. In March 2000 the free encyclopaedia *Nupedia* was launched. It was open-content and peer-reviewed, looking for only expert-written entries, and supported by advertising alongside the entries. The management at Bomis was frustrated with having to fund Nupedia. In January 2001 Sanger complained to computer programmer Ben Kovitz about the slow rate of growth, because of the peer-reviewed submission of entries process, and he was introduced to the concept of a *wiki*. Kovitz suggested that adopting the wiki model would allow editors to contribute simultaneously and incrementally throughout the project, thus breaking Nupedia's bottleneck. Sanger proposed it to Wales, and they created the first Nupedia wiki on 10 January 2001.

WALES ON NUPEDIA

‘*THE IDEA was to have thousands of volunteers writing articles for an online encyclopaedia in all languages. Initially we found ourselves organising the work in a very top-down, structured, academic, old-fashioned way. It was no fun for the volunteer writers because we had a lot of academic peer review committees who would criticise articles and give feedback. It was like handing in an essay at grad school, and basically intimidating to participate in.*’ Jimmy Wales on the Nupedia project, *New Scientist*, 31 January 2007

WHO INVENTED THE WIKI?

HOWARD G. ‘Ward’ Cunningham (b.1949) developed the *wiki* in 1994–5. ‘Wiki’ is the Hawaiian word for quick or fast. It is a user-editable website that allows the creation and editing of any number of interlinked web pages, via a web browser using a simplified markup language or a WYSIWYG (‘what you see is what you get’) text editor. Wikis are usually powered by wiki software and often used collaboratively by multiple users. As a software technology for websites, it allows multiple users to edit and update a text or program quickly and easily. Cunningham started programming the software he called *WikiWikiWeb* in 1994 and installed it on the website of his software consultancy in 1995. Cunningham originally described his software as ‘*the simplest online database that could possibly work*’.

The wiki was initially intended as a collaborative project for the public to write articles that would then be reviewed for publication by Nupedia's expert volunteers. The majority of Nupedia's experts, however, wanted nothing to do with this project, fearing that mixing amateur content with professionally researched and edited material would compromise the integrity of Nupedia's information, and damage the credibility of the encyclopaedia. The wiki project, named *Wikipedia* by Sanger, went online at a separate domain just five days after its creation. Wildly popular, it rapidly outgrew Nupedia because of its lower barriers to contribution and its lower costs. While Sanger saw Wikipedia primarily as a tool to aid Nupedia development, Wales felt that Wikipedia might have the potential to become a truly collaborative, open source contribution to knowledge building. Sanger left Wikipedia in 2002 and, because of what he saw as its lack of respect for expertise, set up *Citizendium* in 2007. It is a more accountable free-access encyclopaedia, but even now has only 15,000 articles. In a 2004 interview, Wales outlined his vision for Wikipedia: '*Imagine a world in which every single person on the planet is given free access to the sum of all human knowledge. That's what we're doing.*' Sanger said in 2005: '… *the idea of an open source, collaborative encyclopaedia, open to contribution by ordinary people, was entirely Jimmy's, not mine, and the funding was entirely by Bomis…the actual development of this encyclopaedia was the task he gave me to work on.*'

REFERENCES

The research for writing non-fiction has become easier every year for this author. We can now Google a topic, and invariably the first ‘hit’ is Wikipedia, an absolutely invaluable resource for researching almost any topic. Its greatest value, however, is in uncovering original sources, such as books, newspaper cuttings, broadcasts and the like, to enable one to have an informed opinion upon the subject matter. Also of great importance to historical research is Project Gutenberg, which has over 36,000 free out-of-copyright books of historical importance online. Each of the subjects in this book has up to 20 or more sources of information, so a full bibliography would be as long as the book. The following is a select list of the most useful sources of information for anyone wishing to research the history and importance of inventions and discoveries. As such, it is broken down into the some of the most useful published books and websites.

Books:

Bridgman, Roger, *1000 Inventions and Discoveries*, Dorling Kindersley in association with The Science Museum 2002

Challoner, Jack, *1001 Inventions that Changed the World*, Cassell 2009

Tallack, Peter (editor), *The Science Book*, Cassell 2001 – an illustrated history of science featuring 250 significant milestones in the history of scientific discovery.

Websites:

http://inventors.about.com

A superb website. It has a useful timeline of all known inventions, an A–Z of inventions (from adhesives-glue and adhesives-tape to zipper) and an A–Z of inventors (from Acheson to Zworykin).

http://science.discovery.com

Gives us the Science Channel’s 100 Greatest Discoveries, in the categories astronomy, biology, chemistry, Earth science, evolution, genetics, medicine and physics.

www.sciencetimeline.net
Begins around 10,000 BCE when wolves were probably first domesticated, and ends in 2001 with Agrawal's method for determining with complete certainty whether or not a number is a prime number. There are thousands of entries and a superb bibliography.

http://videos.howstuffworks.com/science Leads you to 100 short videos detailing the 100 Greatest Discoveries beginning with A Disk of Stars (Herschel) and Atomic Weight. There is an irritating opening commercial, but the presentation is excellent.

www.wikipedia.org
The largest online encyclopaedia, a starting point for most research. It has portals on the *History of Discovery*, *List of Discoveries*, *List of Inventors* etc.

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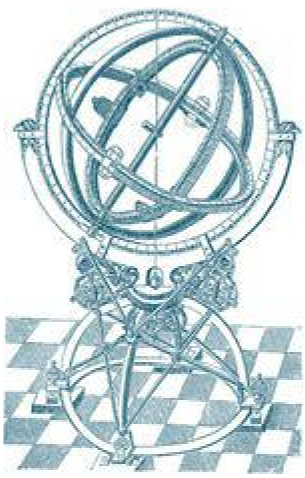

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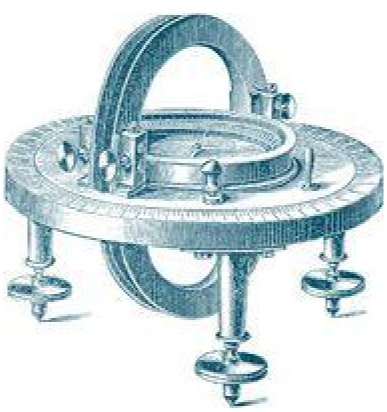

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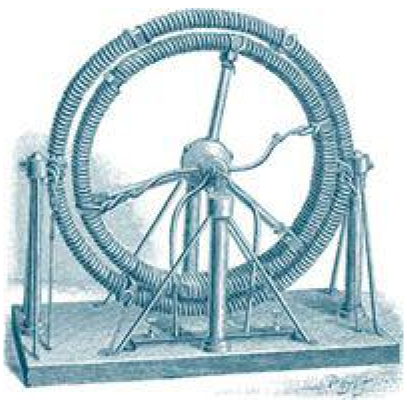

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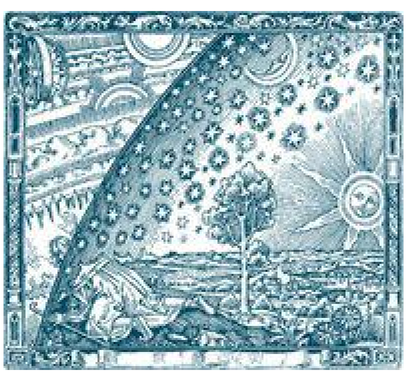

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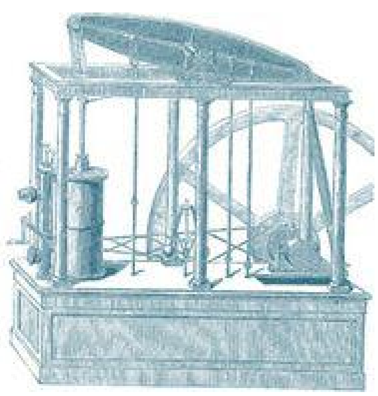

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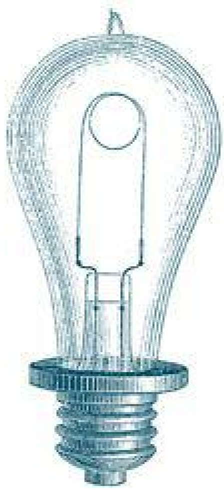

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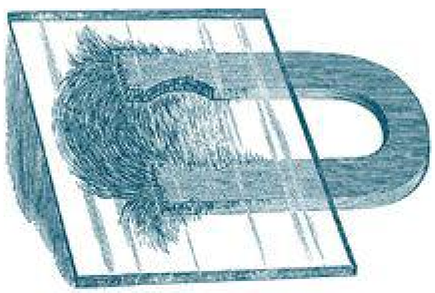

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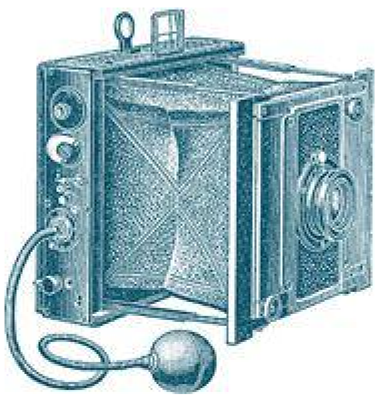

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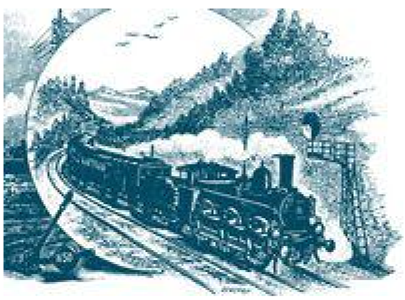

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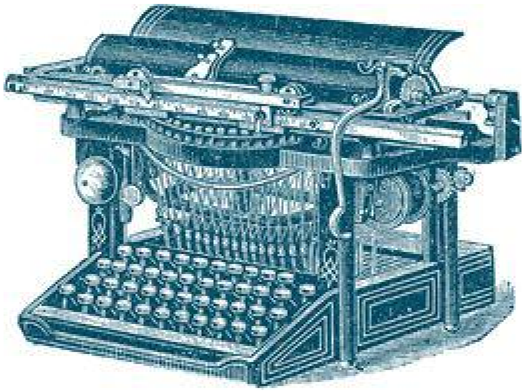

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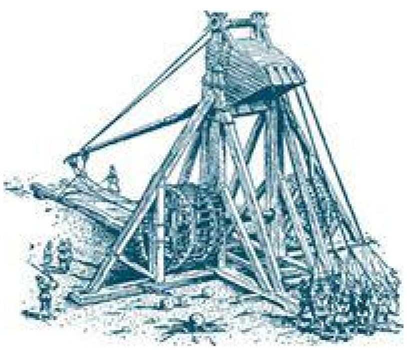

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